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OCTOBER 1924

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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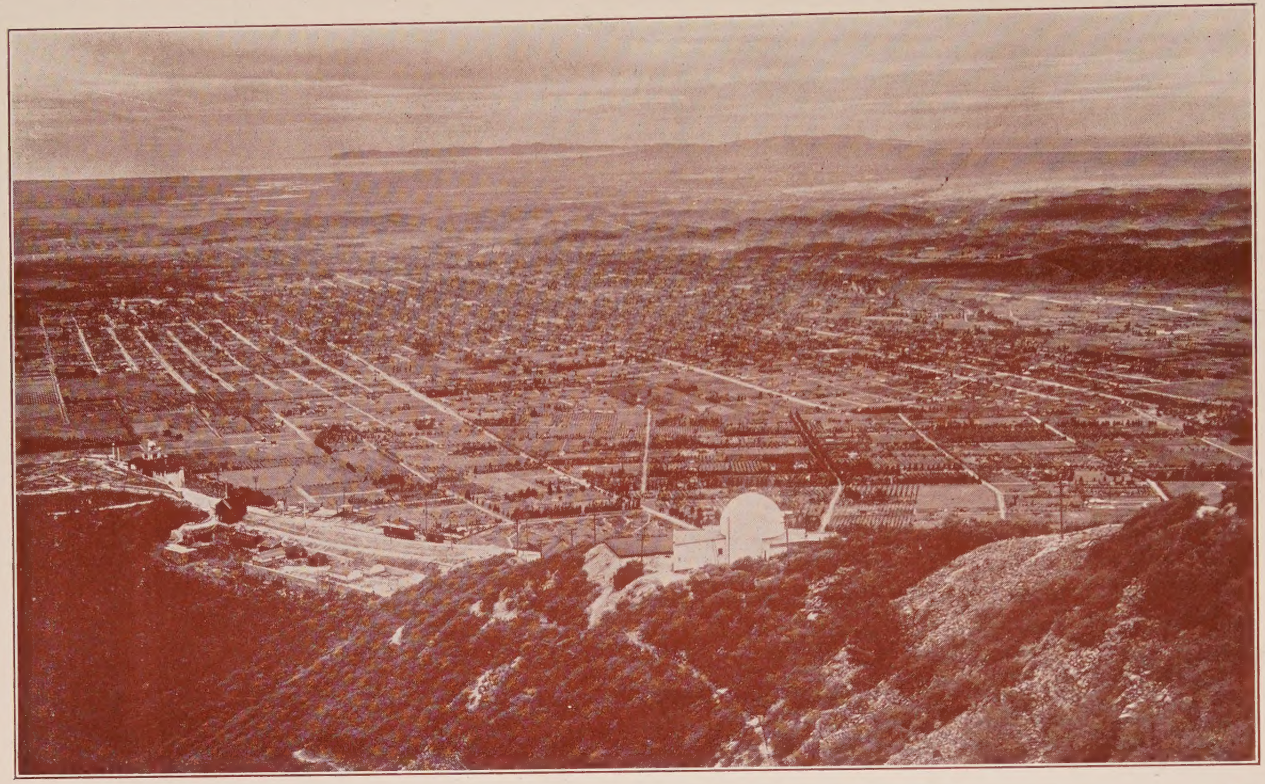
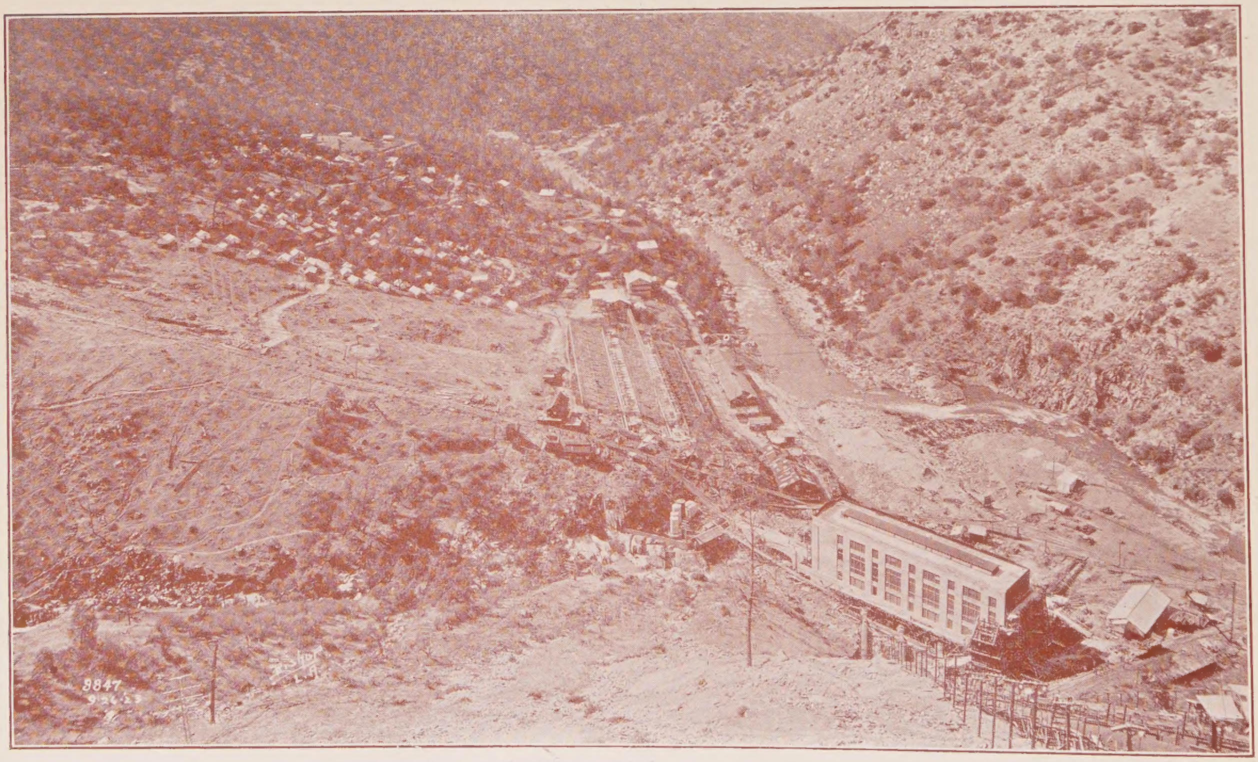
PACIFIC COAST CONVENTION NUMBER

Birdseye View of Pasadena with Mt. Wilson Observatory in Foreground



The Pacific Coast Convention, Pasadena, Cal.

October 13-17, 1924



Big Creek Station No. 3 During Construction—Installed Capacity 75,000 Kw.

JOURNAL

OF THE

American Institute of Electrical Engineers

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American Institute of Electrical Engineers

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Midwinter Convention, New York, N. Y., February 9-13

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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

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Some Considerations of the Meetings and Papers Committee

The first meeting of the Meetings and Papers Committee for the season of 1924-5 was held at the Institute Headquarters on September 12th. The Committee for the present season has been somewhat enlarged, as its membership includes the chairmen of practically all the Institute committees having to do with the technical work of the Institute and the chairmen of all Sections, in addition to eight members of the Committee at large.

The object of providing such a large committee was to establish a sort of clearing house for the discussion of general Institute policies with a view to coordinating the work of all the technical committees and formulating plans toward which all of the committees could work in harmony.

The first business of the meeting was the consideration of place and date of conventions. It was decided to hold the Midwinter Convention in New York City February 9-13 and the Spring Convention in St. Louis in the month of April. The exact date has not been fixed. It was also decided to hold the Annual Convention at some point on or near the Atlantic Coast, and the location of the Pacific Coast Convention has been left for the decision of the Pacific Coast Sections.

A new type of meeting was introduced last year in the Eastern District Regional Meeting at Worcester and it was the concensus of opinion of the Committee that in view of the success of this first meeting similar Regional Meetings be encouraged. It is believed that eventually the Regional Meetings may eliminate one or two of the National Conventions.

The type of program for various conventions was considered and it was agreed that the Midwinter Convention should be a working convention with a heavy technical program. The Spring Convention has usually been adapted to the requirements of the neighborhood in which it is held, and some element introduced that would be of special help to the engineers situated around the territory of the convention. There has been some difference of opinion in connection with the June Convention, but the majority opinion seems to favor a very light program of technical papers or even an entire omission of technical papers at this convention and to confine it to the consideration of topics of major interest to the Institute. While no definite conclusions have yet been reached regarding the Annual Convention program, there is a strong sentiment in support of devoting a great deal of the time to social and entertainment features and the balance of the time to technical committee reports, Institute policies, discussion of Section activities and perhaps one or two symposiums on subjects of outstanding interest to electrical engineers.

The Pacific Coast Convention programs have been largely contributed by the engineers on the Pacific Coast in former years. This year the program has been more widely contributed from all parts of the country, which gives the meeting this year more of the aspects of a National Convention.

A great deal of consideration was given to the methods of obtaining and handling the Institute papers. It is the belief of the Committee that the production of papers has been such that it will be one of the least of the technical committee's duties to provide additional papers. In view of the large number of papers which are available and are received without solicitation, one of the principal duties of the technical committees will be to urge improvements in the quality of the papers and to discourage the quantity production.

The methods of cooperation between the Meetings and Papers Committee and the various Sections in connection with regional meetings was discussed at length and a subcommittee was appointed to draw up a tentative working plan for regional meetings in cooperation with the Sections Committee, and to submit such plans to the Meetings and Papers Committee for future discussion.

Other subjects discussed at considerable length at this meeting included preparation of a code of conduct for the Meetings and Papers Committee, the general discussion of committee work and desirable activities of various technical committees, and the possibilities of cooperation in connection with District and Section meetings.

A. I. E. E. Publication Policy Reaffirmed

The first meeting of the newly appointed Publication Committee of the A. I. E. E. was held at Institute Headquarters Wednesday, September 24th, at which there was a general discussion of the status of the work and the policies of publication.

As the amount of money appropriated for the publication of the Journal provides for a definite number of pages per year, it will be necessary to abstract more of the papers, and to make even shorter abridgements than has been the custom in the past. This action was decided upon after careful consideration of the

amount of available papers which still remains to be published this year.

Every effort will be made to print either in full or in abstract in the JOURNAL those articles which have not yet been published, but have been presented at conventions during 1924, by the close of this year, so that the 1925 issues of the JOURNAL will be entirely available for papers presented during next year.

It is the unanimous opinion of the members of the Publication Committee that the present policies which are being followed are in accordance with the desires and suggestions of a majority of our members, insofar as the appropriation and limitations of space permit. After a most careful and painstaking survey of this subject, it has been decided to adhere substantially to the publication policies inaugurated during the past year.

Some Leaders of the A. I. E. E.

Frank Julian Sprague, the eighth president of the Institute, was born at Milford, Conn., July 25, 1857. At twenty years of age Mr. Sprague graduated from the United States Naval Academy, and after several years in naval service resigned to associate himself with Thomas A. Edison in the development of electric lighting systems.

In association with the late E. H. Johnson, Mr. Sprague formed the Sprague Electric Railway and Motor Company, to develop new principles and design of electric motors and electric railways. Sprague motors were exhibited at the Philadelphia Electrical Exhibition in 1884. In May, 1887, a contract was taken for the equipment of the Union Passenger Railway, of Richmond, Va., requiring 80 motors for 40 cars; a complete overhead system and a central power plant. This constituted the first electric railway of commercial magnitude, which developed immediate and wide interest in trolley operation, and trolley lines were soon thereafter in use in various parts of this country and abroad, later being followed by elevated electric railways.

About the year 1890 the Sprague Company was consolidated with the Edison General Electric Company, Mr. Sprague remaining for a time as consulting engineer.

Later he organized the Sprague Electric Elevator Company, introducing satisfactory high-speed electric elevators. He invented the multiple unit system of train control and operation, and was appointed a member of the electrical commission which had charge of the electrification of the New York Central Railroad terminal in New York City, being co-inventor of the protected third rail there used.

He was chairman of committees on electricity and ship construction of the United States Naval Consulting Board during the war period, and is at the present time president of the Sprague Development Corporation, and the Sprague Safety Control and Signal Corporation.

Mr. Sprague was president of the Institute during the term 1892-93. In 1910 he was awarded the Edison Medal by the Edison Medal Committee of the A. I. E. E., and in 1922 was awarded the Franklin Medal by the Franklin Institute. The honorary degree of L L. D. was conferred on him by the University of Pennsylvania in 1924. He was president of the Inventors' Guild in 1916, and is a member of the Engineers, Bankers, University, Century and Railway Clubs, New York.

A. E. S. C. Year Book

The growth in standardization, shown by the American Engineering Standards Committee Year Book, which has just been published reveals remarkable activity in industrial standardization. The work of the Committee is indicative of the growth of the movement as a whole. One hundred and fifty-two standards have been adopted or are under consideration by the present representatives of 235 national, technical, industrial and governmental organizations.

Cooperation in joint activities between Mr. Hoover's Division of Simplified Practise and the American Engineering Standards Committee has steadily increased. In general, the work of the Committee is concentrated upon standardization projects which involve technical considerations, while the Division of Simplified Practise concentrates upon such eliminations as it is possible to carry out from a consideration of statistical production data alone.

In order to meet the demands made upon it by industry, and to supply the needs of the various working technical standardization committees, the American Engineering Standards Committee has greatly broadened its information services, and has added an Engineer Translator to its staff for this purpose. In this way, complete information is made available to sustaining members, trade and technical associations and other inquirers on standardization activities in foreign countries, as well as in the United States.

Through its information service, the A. E. S. C. has on many occasions supplied copies of standards, or details of information based on a study of foreign standards, in accordance with which bids could be prepared intelligently, thus enabling the American firm to submit its bid by cable, when without such service it would have been unable to act in time.

A new development is the appointment of local representatives of the Committee in four important industrial centers. More than 140 national trade associations are officially participating in standardization projects under the auspices of the American Engineering Standards Committee.

Transmission at 220 Kv.
on the Southern California Edison System
A SYMPOSIUM

Review of the Subject.—*The object of this composite paper is the presentation of a fairly complete description of this 220-kv. system and its operation, together with an account of some work which is being done in preparation for a third line to Big Creek.*

The first section is descriptive of the system and the flashover troubles, giving a detailed account of the bird theory for the cause of flashovers and of the evidence substantiating that theory, also of the measures being taken to prevent the birds from causing flashovers.

The balanced relay protection for the lines and the relay installations to control a flashover or other accidental ground in case the balanced relays are not allowed to function, together with some information obtained from a study of flashovers are contained in the second section.

Section three is devoted to a study which is being made to determine the mechanical and electrical characteristics which will give a most economical third line from Big Creek to Los Angeles. Both aluminum and copper conductors of various large sizes and working at various tensions are considered, and tower locations on ten miles of profile were made.

Section four reports that vibration, particularly in the longer spans, has apparently caused some failures of ground wires and possibly of conductors. Frequencies of 13 to 30 cycles per second and amplitudes up to one inch have been recorded. The vibrations are believed to be due to air currents, but no means of preventing them has been discovered.

In order to minimize the effects of vibration, it is proposed to reduce the weight of the dead end clamps so that the shocks will be transmitted to the tower connections instead of being absorbed at the outer end of the clamps as at present. A new light weight dead end clamp has been designed and is being tested under service conditions.

In section five it is concluded that for a high voltage line of large capacity the high cost per mile and heavy tonnage to be transported during construction require careful location work to strike the most economical balance between a straight line and one most easily accessible for construction and maintenance. Right-of-way cost must also be given consideration, together with many other factors which make up the total cost.

The complexity of the problem and the large amount of money involved with consequent opportunity for saving, warrant unusual methods of reconnaissance and survey, and purchasing right of way.

Section 1—Description of System and Operating Experiences

BY H. MICHENER

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Southern California Edison Co., Los Angeles, Cal.

THE single line diagram (Fig. 1) shows the 220,000-volt system of the Southern California Edison Company. The lines from Big Creek No. 1 through Big Creek No. 3 to Eagle Rock are 243 miles long. The taps to Laguna Bell start about three miles from Eagle Rock and are 26 miles long. From 1913 to 1923 the lines from Big Creek to Eagle Rock operated at 150,000 volts. Since May 1923 the system as shown has been operating at 220,000 volts.

Fig. 2 shows the anchor tower with dead end insulators.

Fig. 3 shows the standard tower with suspension insulators and with a 10-foot extension under it. On account of the increase in the legal minimum clearance from conductor to ground, it was necessary, when reconstructing for 220,000 volts, to install five, ten or fifteen-foot extensions of this type under 2150 towers out of a total of 3340. The greater number of these was raised with the lines energized. Fig. 4 shows one being raised.

The conductors on the lines from Big Creek to Eagle Rock are of 605,000 cm. aluminum with 78,500-cm. steel core. The insulators have 12 units in a suspension string and thirteen units in each of the two parallel dead end strings which are three units and two units more respectively, than when operating at 150,000 volts.

To be presented at the Pacific Coast Convention of the A. I. E. E., Pasadena, Cal., October 13-17, 1924.

Figs. 5 and 6 show the two types of towers for the branch lines to Laguna Bell. These are new lines designed for 220,000 volts. The conductors are 666,600-cm. aluminum with 85,400-cm. steel core. The insulators have 13 units in a suspension string and 15 units in each of the two parallel dead end strings which are the numbers that would have been put on the old lines if the tower dimensions had permitted.

The shield rings are made of cast aluminum, with the exception of those at the top of the suspension strings. Copper or iron shield rings would be less damaged by an arc and would constitute less fire hazard. When flashovers occur, the aluminum of the shield ring melts and actually burns while falling to the ground. This sets fire to any inflammable material with which it comes in contact. Several bad grass fires were started in this way and it was necessary to clear the grass away from the towers. Flashovers had caused fires before the aluminum shield rings were installed but to a less extent in proportion to the number of flashovers. As a laboratory check on the belief that the aluminum actually burns, *i. e.*, combines with the oxygen of the air with sufficient rapidity to cause heat and fire, arcs were established between small wires of various kinds of metal. The copper and the iron wires melted, the molten metal became a dull red before reaching the floor and did not set fire to the shavings which had been sprinkled on the floor. When the arc was established between the aluminum wires there was a shower of sparks which remained white hot and burning for an appreciable length of time after reaching the floor and which immediately set fire to the shavings.

Practically the only operating troubles ever experi-

enced on the Big Creek lines have been insulator flashovers. During the ten years of operation at 150 kv. they occurred at the rate of about 16 per year. After the line was energized at 220 kv., the number of flashovers increased materially and were for the various months from May, 1923 to June, 1924 inclusive, as follows: 6, 5, 12, 14, 9, 10, 8, 1, 4, 3, 3, 0, 0, 1. When August, 1923 passed with its 14 flashovers, it was necessary to abandon the policy of trying one preventative at a time in search for the one which would stop the flashovers and, instead, to try at once all the possible preventative measures that could be conceived. This work was started early in September and, together with the more systematically planned work of the immediately preceding months, began to bear fruit in decreased numbers of flashovers.

carded as a cause of any considerable number of the flashovers. The flashovers occurred so infrequently in those days that the number of observations from which to draw conclusions was small. It took five years after operation began to accumulate as many flashovers as occurred during the first year of 220-kv. operation.

Two or three years ago one of the men in charge of the lines saw a bird, just as it was leaving the tower, drop a stream of stringy excrement which extended from the tower member above the insulator to a point as low or lower than the conductor. The observer was apprehensive of a flashover until the stream had fallen clear of the tower without coming in contact or within arcing distance of the conductor. The bird was reported to have been an eagle.

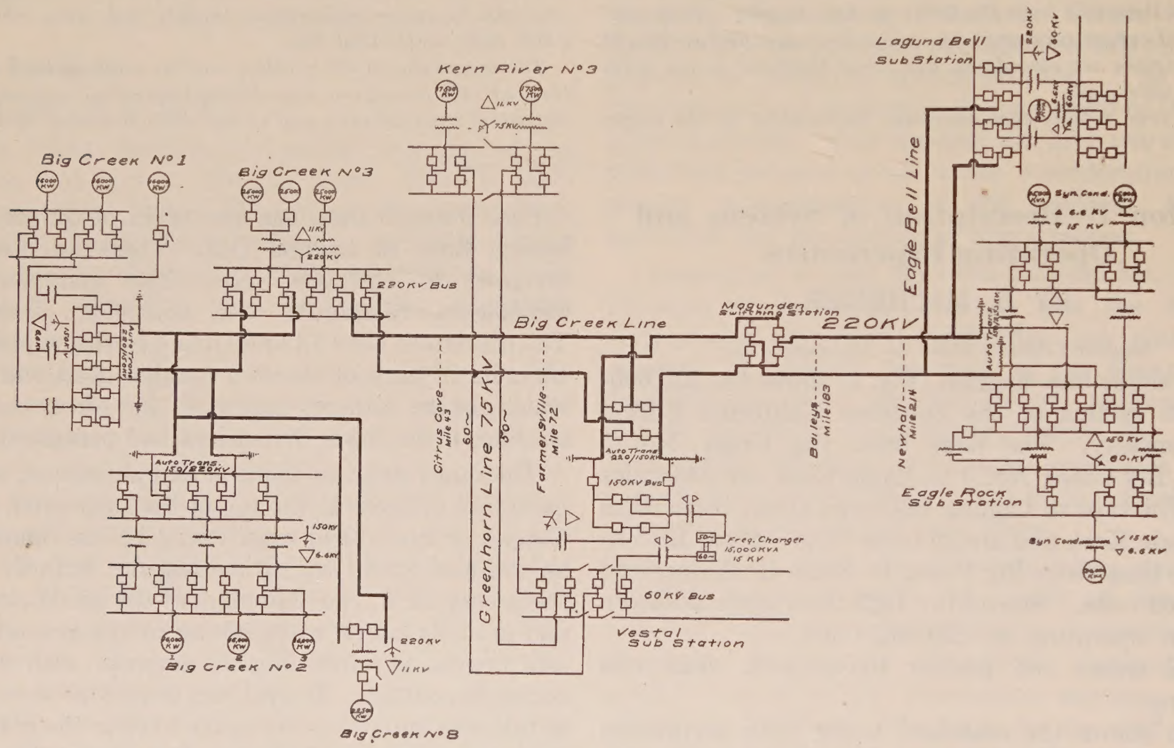

FIG. 1—SINGLE LINE DIAGRAM OF THE 220,000-VOLT SYSTEM OF THE SOUTHERN CALIFORNIA EDISON CO.

A large part of the work done in the effort to prevent flashovers was predicated on the belief that they were caused by the semi-liquid excrement of large birds, hawks and eagles, at the time it fell over the string of insulators or through the air close to them, thus short-circuiting a considerable portion of the air along the insulator string.

The bird theory of flashovers was given consideration several years ago, soon after the lines began to operate at 150 kv., but no evidence to support it could be obtained. The idea in mind at that time was that the accumulation of bird dirt on the insulators would be the only way that the birds could be responsible for flashovers. Some of the strings which fastened over were found to be clean so the bird theory was dis-

At nearly all the towers where flashovers have occurred during the last two years, direct evidence that a bird was the cause has been found. To facilitate the description of this evidence assume a particular case. The direction of the line is north and south. Three or four feet east of the point of support of the insulators a streak of bird excrement and a spot burned by the arc were found to coincide on the crossarm member. Burned spots were found extending from this point along the crossarm member to a point eight or ten feet on the west side of the insulator.

On the east side of the shield ring a spot of bird excrement and a burn from the arc were found to coincide and burns from the arc extended around the ring to the west side.

The conclusions drawn are that the bird was sitting on the tower some distance to the east side of the point of support of the insulator string and the wind was blowing toward the west with sufficient force to cause

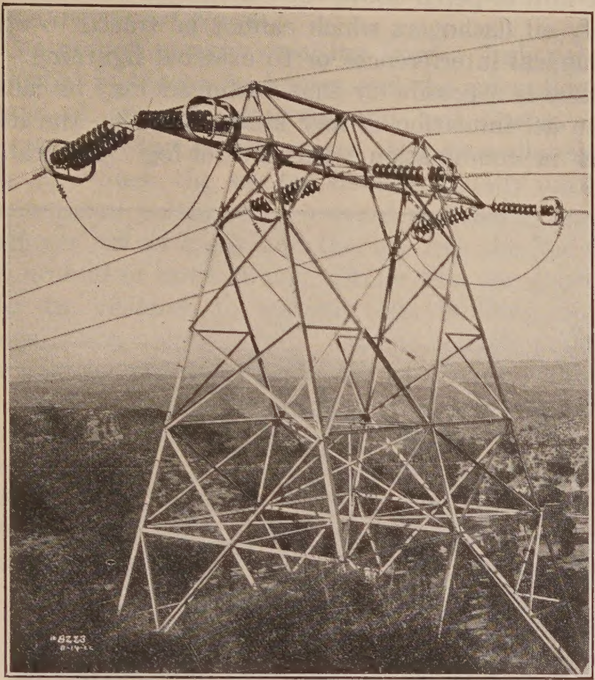

FIG. 2

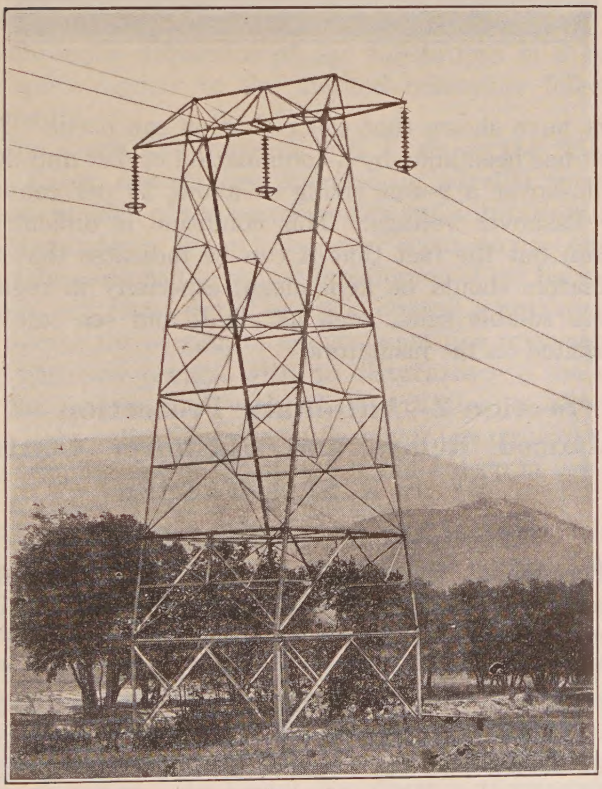

FIG. 3

the stream of excrement to strike the shield ring and start the arc. The wind then blew the arc across the insulator string, the top traveling along the tower and the bottom around the shield ring.

The above is a special case and is subject to many modifications according to the position of the bird and the direction and strength of the wind. It is not necessary that the stream of excrement actually strike the energized parts. In the case of a dead end tower the arc is started between the jumper loop and the crossarm members.

The greater number of flashovers has occurred on the sections of the lines where there have been the most

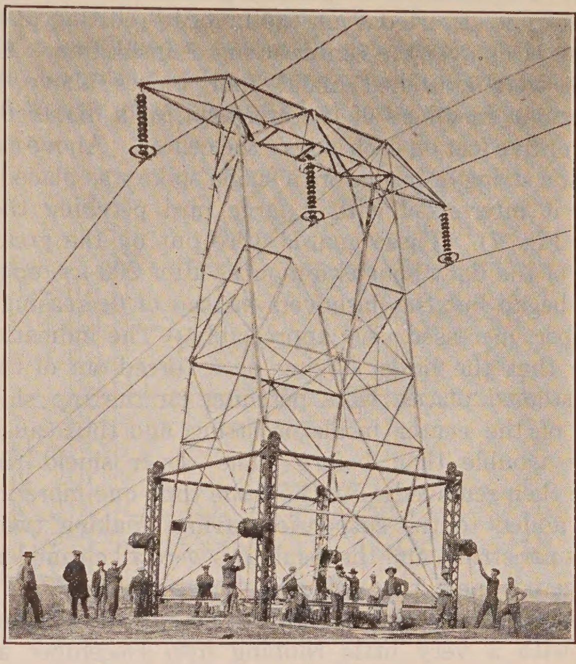

FIG. 4

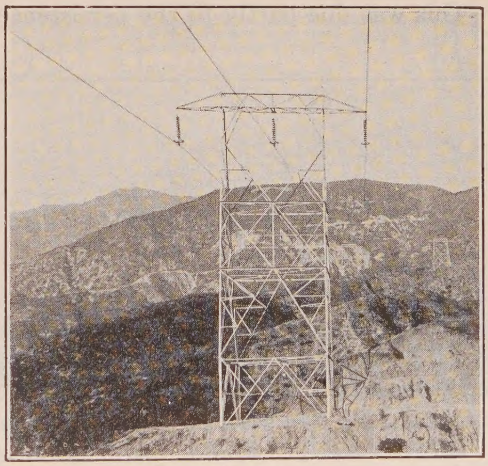

FIG. 5

birds as indicated by the greater amount of bird dirt on the insulators when cleaned a few months ago. Also the insulators on the center conductors have had more than seventy-five per cent of the flashovers during the last four years. These insulators were much more dirty from birds than those on the outside conductors.

F. W. Peek, Jr., in his high voltage laboratory, set up an 11-unit string of insulators, mounted a $\frac{3}{8}$ in. tube,

with cork in the bottom, on the tower near the top of the insulator string. Then by putting one or two ounces of a starch-salt solution in the tube and pulling the cork out by a string, flashover occurred at normal voltage when the stream flowed down over the insulators and also when it fell through the air near the insulators but touched neither the insulators nor the energized parts at the bottom of the insulators.

The first attempt to prevent the birds from causing flashovers consisted of placing guards made of steel strips in an inverted V on the favorite roosting places of the birds over the center string of insulators. Also wires were stretched about four inches above the horizontal members of the crossarm for a distance of four or five feet on each side of the center. Above each outside string of insulators a single spike was placed so that it interferred with a large bird perching there (See Fig. 7). These guards were put on the greater part of the line about two months after 200-kv. operation began but the flashovers instead of decreasing in number, increased very appreciably. The indications were that the birds, having been forced out of their accustomed places, were perching on the top shield ring of the center insulator string and thus causing more trouble than before. The upper shield rings were then removed. At the same time one more unit was added to the suspension strings making twelve units per string, and the insulators were all cleaned and meggered, and the defective units replaced. This work was done during September, October and November with a very little running into December and January.

The flashovers continued at the rate enumerated above. This was due partly to the persistence of the

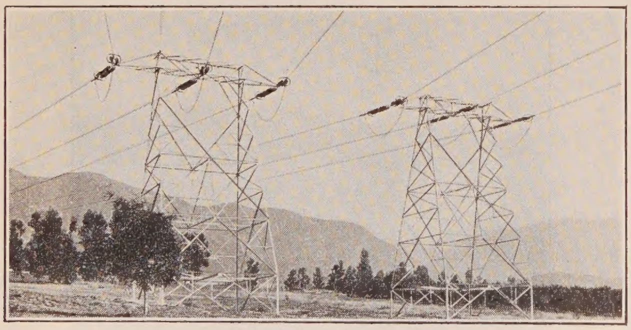

Fig. 6

birds in crowding into their old perching places and partly to the fact that no bird guards were placed on the dead end towers. The proportion of flashovers occurring on dead end towers increased after bird guards were placed on the suspension towers.

Because the flashovers were continuing, though at a diminished rate, 60 miles of line were equipped with galvanized iron pans in the crossarm above the center strings of insulators. They were about 4 by 8 ft. with the center above the insulators. They were installed in Feb. 1924, and no flashovers have occurred in this section since then. However, only four flashovers have occurred on the whole line during that period.

It is believed that guards which will not allow any large bird to perch above the conductors will eliminate nearly all flashovers which cannot be traced to other mechanical interferences or to external lightning.

There is a possibility that flashovers may be caused by an accumulation of any kind of dirt on the insulators in combination with dew or fog. Laboratory

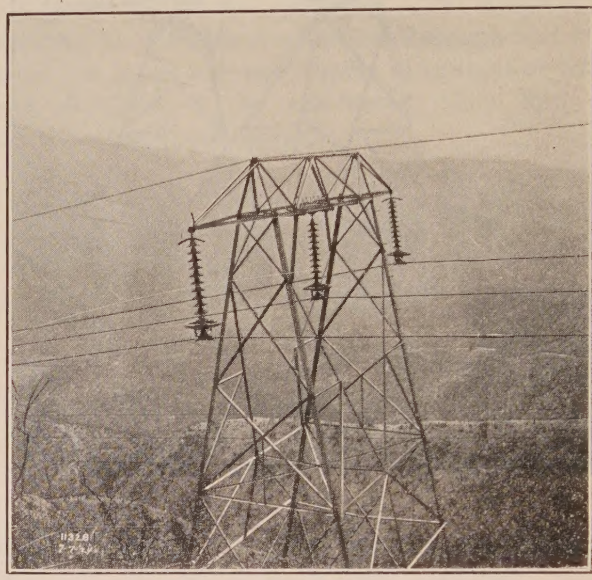

Fig. 7

tests have shown that this condition can occur. Mr. Peek has been able, by a combination of dirt and dew, to flashover a 9-unit string at about 20 per cent its dry flashover voltage. This condition is difficult to obtain but the fact that it can be indicates that the insulators should be kept clean, especially in regions where soluble salts, such as alkali and sea salt are deposited on the insulators.

Section 2—Automatic Protection—Balanced Relays and Flashover Control

BY. E. R. STAUFFACHER
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Throughout the history of the Big Creek transmission line there have been flashovers which would occur occasionally at no particular interval and at no particular season of the year or time of day. This was the case when operating at both 150 kv. and 220 kv. These flashovers would occur in the proximity of an insulator string, would result in grounding one of the wires and would cause an interruption to the service. The operators became expert in handling these flashovers with the original installation of two units in each Big Creek No. 1 and Big Creek No. 2 and the synchronous condensers in Eagle Rock and the interruption resulting from a flashover was very short. When

the system became more complicated by the addition of the frequency changer and the Kern River No. 3 connection at Vestal, with more generating stations at Big Creek, the manual control of flashovers did not give such good results. The procedure under manual operation was as follows:

The ground current resulting from a flashover was indicated in the power houses and the substations by means of ground ammeters and bell alarms. The operators at the power houses then immediately began to reduce the exciter fields manually until the transmission voltage was lowered sufficiently for the flashover arc to break and thereby free the line from this ground or short circuit. After this the generator field was restored to normal, thus building up the transmission voltage again. At the receiving stations the practise was to open the field on the synchronous machines upon the occurrence of a flashover, thus allowing these machines to operate as induction motors until the flashover was cleared by lowering the voltage at the generating end. When the voltage was up to normal, the frequency changer and the synchronous condenser fields were again closed. As a result of the successful use of balanced relays on some of the important trunk lines of the 60-kv. transmission network, similar relays were adopted for the 220-kv. system, and at the same time it was decided to install equipment which automatically would accomplish the function of lowering the voltage of the generators and opening the fields of the synchronous apparatus at the substations in a manner quite similar to the method heretofore followed manually.

The single line diagram, Fig. 1, shows the 220-kv. Big Creek circuits are operated in parallel through busses at each of the power houses and substations and at Magunden. When a flashover occurs in any one of the four sections the proper functioning of the balanced relays will cause switches to be opened automatically to isolate the section of transmission line upon which the flashover occurs, with no disturbance to the rest of the system and with no interruption to service. The only indications that a flashover has occurred are the tripping out of the switches and a drop in voltage for a period of two to five seconds.

At each sectionalizing point the balanced relays installed are connected to bushing-type current transformers in the oil circuit breaker terminals. Upon the occurrence of unbalance in the current flowing in the two lines, these balanced relays close their contacts, trip out the proper switches and thus disconnect the section of line in which the trouble has occurred. At some of the stations the relay system is more complicated than at others. At Vestal, for example, it was necessary to balance the sum of the currents flowing in two oil circuit breakers and one auto-transformer connected to one line against the same for the other line. This is accomplished by means of paralleling the current transformers in the apparatus concerned. Due to the possibility of a dangerous rise in voltage should some automatic operation separate the generating end from the receiving end of the transmission line, the tripping connections of the oil circuit breakers were so arranged that after the circuit breakers of one line are operated, those of the second line would immediately become non-automatic. With such connections, the removal of one line from service for any purpose renders the remaining line non-atuomatic and leaves the service exposed to the risk of a comparatively long interruption with only manual protection. To provide against such a contingency automatic flashover control equipment operating on the generator voltage was installed.

A master relay connected in series with the second-

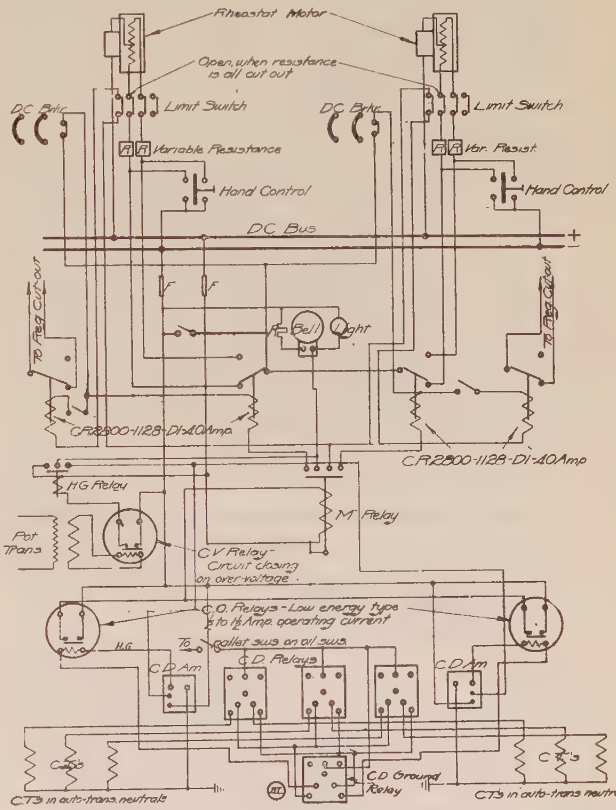

Fig. 8

aries of the current transformers in the grounded neutral of the power transformers is so arranged that when the ground current passes through this relay, due to a flashover, the relay contacts will close and operate a number of auxiliary relays. These auxiliary relays will cause the motor-driven rheostats to cut in resistance in the field of the exciters at the various generating plants until the voltage is lowered sufficiently to break the arc, thus eliminating the flashover from the line. The master relay is then returned to its original position, which, by means of the auxiliary relays, will cause the motor-driven rheostats to go back to their original position, thus bringing the voltage back to normal. Simultaneously with the lowering of the voltage at the various generating plants, the ground currents at the

terminal substations and at Vestal operate relays which automatically lock open the master circuits of the field regulators of the condensers and frequency changers, thus introducing the maximum resistance in the exciter

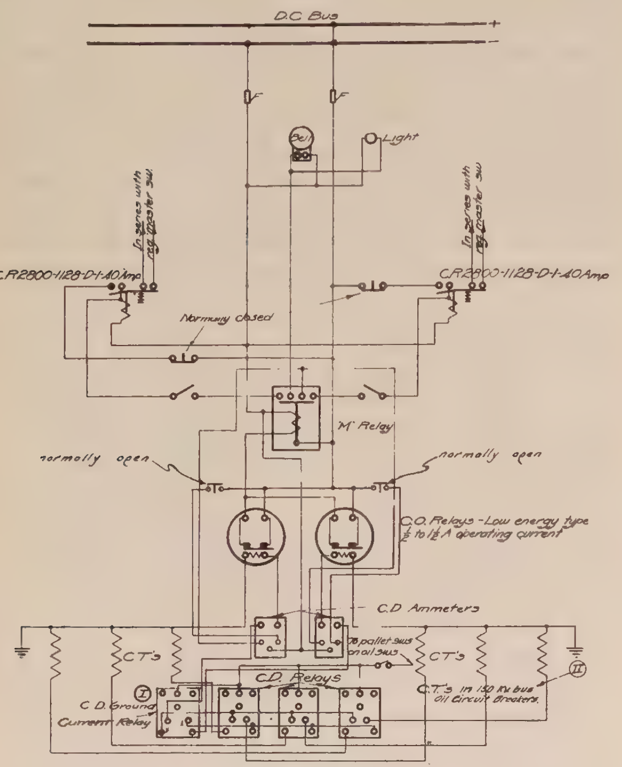

Fig. 9

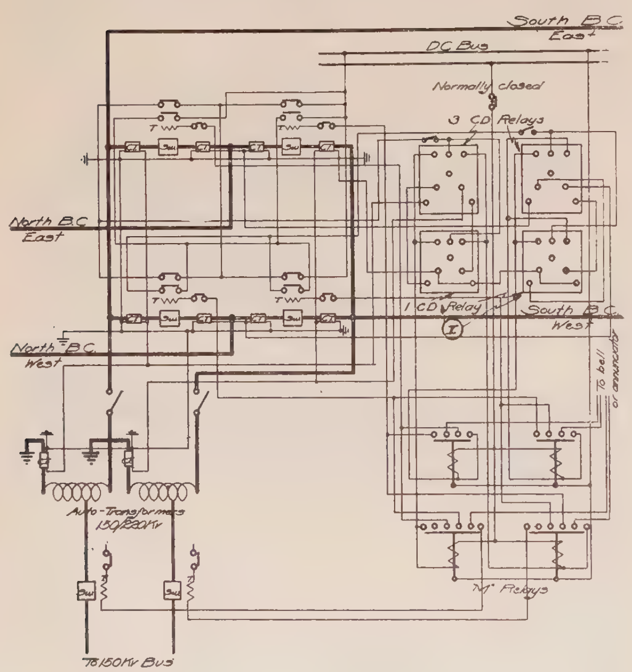

Fig. 10

field. When the arc is broken and the condensers and frequency changers are returned almost to synchronous speed, the master relay is released by a push button, thus allowing the regulator to bring the excitation of the condensers and the frequency changer back to normal.

The time required to handle the flashovers, when two lines are in parallel and the balanced relays operative, is from two to five seconds. When line conditions are such that the balanced relays cannot operate, about 30 seconds is required to handle the flashover, either by the manual method or by means of the automatic suppressor. Of this time 10 seconds is required to bring the voltage down to the value where the arc will break and approximately 20 seconds is consumed

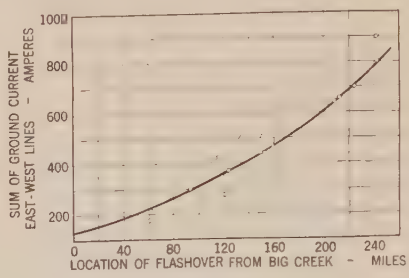

Fig. 11—Ground Current—Eagle Rock 220-Kv. Flashovers East-West Lines. (East-Line Short Circuits)

in restoring the voltage to normal. However, a rheostat in series with each of the motor circuits is so connected that it will permit varying the above time interval in lowering and raising the voltage as experience dictates. The use of these rheostats makes it possible to calibrate all equipment at generating plants, so the voltage can be lowered simultaneously throughout the Big Creek generating system regardless of the characteristics of the individual generators. Figs. 8, 9 and 10 give detailed wiring diagrams and explanation of the connections for the balanced relays and the

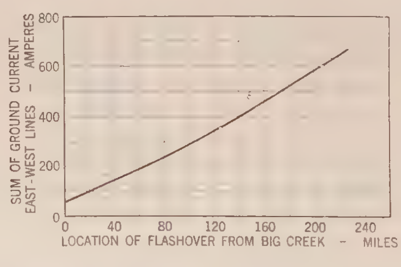

Fig. 12—Ground Current—Eagle Rock 220-Kv. Flashovers East-West Lines. (West-Line Short Circuits)

automatic flashover control for Big Creek No. 1, for Eagle Rock, and for the balanced relays only at Vestal. The connections at the other stations are similar with only slight differences where local conditions demand. Knife switches are included in the connections so that any part of the equipment can be rendered non-automatic at will.

Careful studies of the flashovers have been made with reference particularly to location, time, duration weather at point of flashover, voltage, ground current, and kv-a. connected at each of the stations, damage

done by the flashover, and relay operation. Cases in which the trouble was cleared by the relays caused less damage than others.

A study of the ground currents at the time of a flashover shows that these currents vary roughly with the distance between the flashover and the major generating plants or major substations. Curves indicating this are given in Figs. 11 and 12. In the curves the locations are given in terms of miles from Big Creek and it will be noted that as the distance from Big Creek increases, the amount of ground current flowing from Eagle Rock also increases. This is undoubtedly due to the decrease in ground circuit resistance, as the distance between Eagle Rock and the point of flashover is decreased.

Since the time of placing the balanced relays in operation (August, 1923), the performance has been very satisfactory. A comparatively short time has elapsed since the entire 220-kv. line has been placed under automatic protection and there has been no opportunity to study the clearing of flashover in the section south of Magunden. There have been a number of operations on the two sections between Big Creek No. 3 and Vestal and from Vestal to Magunden. At the time of the greater number of these relay operations there was no interruption to service. The relays were first set for a current unbalance of 350 amperes. On the first two cases of trouble following the installation of the relays, those on the end of the section in trouble toward Big Creek operated properly but those on the end toward Eagle Rock did not operate, because there was not sufficient energy supplied from the Eagle Rock end to cause as great unbalance as 350 amperes. After the second occurrence, the relay setting was lowered so that only 300 amperes unbalance was necessary to cause the relay contacts to close. Since that time the relay operations have been satisfactory in all cases, clearing the trouble from two to five seconds, and giving since installation 13 perfect operations out of 15 opportunities.

Section 3A—Economic Studies of Transmission Line Design with Particular Reference to the Mechanical Features

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The concrete example of the studies for a new 220-kv. line to the Big Creek water power plants will be used in presenting methods for arriving at the economic conditions of design for this article. The method used was as follows:

Ten miles of actual profiles of an existing transmission line which traverses practically the same route as that to be followed by the new line were taken and so chosen as to represent three miles of level profile; three miles of rolling profile and four miles of mountainous profile. On these profiles were plotted the actual tower locations for the following various materials and conditions.

Tension—between 12,000 lb. and 24,000 lb. on steel reinforced aluminum cable having aluminum of 666,600, 1,000,000, 1,250,000 and 1,500,000 circular mil sizes. Copper of equal conductivity to the size of aluminum mentioned above were tried with several working stress values. There were naturally several heights, strengths and spacings of towers and also numbers of extensions required to meet the conditions of the various sizes of wires and unit stress variations.

The spacing of the conductors was fixed at 22 ft., because of the requirement to have six feet of clearance to ground under maximum conditions of swing.

A sufficient number of points was plotted for each condition to permit of the drawing of a curve. The span and the tension which would give the most economical cost were then taken from these curves and referred to the calculations for electrical conductivity economy, the different phases of which are discussed in another part of this paper. The electrical and mechanical studies are interdependent and were conducted in close cooperation.

In the case of the aluminum cable, it was found for the amount of current to be carried about a million circular mils of aluminum were necessary. The economical tension was about 12,000 lb. and by insisting that a factor of safety in the steel core be such that the maximum working load be 10 per cent less than the elastic limit of the steel core, a cable with the following characteristics was determined on: 1,033,500-cm. steel reinforced cable with either 7 or 19 strands of steel of equal cross sectional area and 54 strands of aluminum.

The same set of economical studies was made with reference to the use of copper conductor. The different tension and tower locations were plotted on the same profiles as were used for the aluminum cable. One of the electrical requirements in the use of the copper was that the outside diameter of the cable be not less than 1.1 inches, so investigation was made on a recently manufactured cable which had two layers of copper stranded on a flexible tube. By plotting total values of cost for completed line for the various tensions, tower locations and tower heights, curves were drawn between the points and the minimum condition was determined, and the point where a rise in cost started was also determined which gave a little range in conditions to permit them to be fitted to the varying profile of an actual line.

A certain limitation was imposed in the use of tension values which was fixed as a maximum, the use of two strings of high strength insulators having a predetermined maximum tension value. This tension, used in its maximum proved economical for both the aluminum and for the copper. To date, however, there has been no definite decision as to which of the materials for cable will be used, hence no definite conclusions can be

stated, but for the copper cable the following sizes were determined:

One of 650,000 circular mils stranded on flexible copper tube having an outside diameter of 1.1 inches. Also a stranded copper cable with 800,000-cir. mils having an outside diameter of 1.03 inches. Of the two sizes the 650,000-cir. mils cable used at a maximum tension value of 12,000 lb. was found to be the more economical. The tower design was based on using a steel of high elastic limit, which material has been found to represent a saving in the cost of the line.

Specially designed attachment details were developed and tested. The principal point which was especially considered was a form of attachment to the cable which would minimize the effect of vibration. Tests are now being conducted on the attachment to determine this effect.

It will be noted that a tremendous amount of calculating is necessary to arrive at the minimum values, but it seems that changes in tension, heights of towers, and spacing of towers impose so many variables that no system better than the curve plotting method will satisfy.

(To be continued)

The Guided and Radiated Energy in Wire Transmission

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THE object of this paper is to give a brief preliminary account, without mathematical details, of the results of a mathematical investigation of wave propagation along wires. This investigation had its inception in the problem of radiation from transmission lines, which was discussed by the writer some time ago.[1] It was found that, in order to completely and directly account for radiation phenomena, it was necessary to recognize the incomplete and approximate character of the usual engineering transmission theory, discard the special assumptions underlying it, and develop the theory *ab initio* from Maxwell's equations. Theoretically interesting and instructive deductions followed from this study, which are believed to justify the present preliminary discussion, which the writer hopes to supplement with a paper dealing with the mathematical theory.

The engineering theory of guided transmission along wires is based on the *transmission equation* in accordance with which the current and voltage are simple exponentially propagated waves, and the transmission phenomena are completely determined by the *propagation constant* and *characteristic impedance* of the line. This theory, however, is incomplete and represents the actual wave with theoretical exactness only at a great distance from the physical terminals of the line. In particular, it ignores the accompanying waves which must be taken into account, in order to directly explain the radiation and scattering of energy from the system.[2]

To put the problem more concretely, consider a transmission system composed of N wires, parallel to the axis of transmission Z, and extending from $z = z_1$ to $z = z_2$. At the boundary planes $z = z_1$ and $z = z_2$ the system is terminated in any desired manner; for example, the wires may be individually connected to N wires of different electrical and geometrical constants or they may be terminated in interconnecting networks, which contain sources or sinks of energy. Now from the viewpoint of elementary transmission theory, the phenomena are completely determined by the current and "potentials" of the N wires. Furthermore, from this same viewpoint the boundary conditions at the physical terminals of the system are simply the continuity of the N currents and the N potentials, and these boundary conditions admit of satisfaction by the N direct and N reflected waves derivable from elementary theory. From the rigorous view-point of electromagnetic theory, however, the boundary conditions require that the electric and magnetic vectors must be everywhere continuous throughout the boundary planes $z = z_1$ and $z = z_2$. Obviously these conditions cannot be satisfied in general by the elementary solution of circuit theory, but require that the complete wave in the region $z_1 \leqq z \leqq z_2$ be represented in effect by an infinite number of component waves, all of which can exist independently in this region, and which individually satisfy Maxwell's equations and the geometry of the conducting system.

To bring out the significance of the foregoing, two simple transmission systems will be briefly considered. First, consider a conducting system composed of a central wire or core, surrounded by a dielectric space and by an external concentric return conductor, thus representing more or less closely the case of a submarine cable. Let this system extend along the positive Z axis. In accordance with engineering theory, transmission along this system is completely determined by

1. JOURNAL A. I. E. E. October, 1921.

2. It may be remarked, however, that the radiation of energy is calculable indirectly to a very good approximation without the explicit recognition of the accompanying waves which actually account for the phenomena. See papers by the writer (JOURNAL A. I. E. E., October, 1921) and by Manneback (JOURNAL A. I. E. E., February, 1923). The explanation of this apparent anomaly is discussed below.

To be presented at the Pacific Coast Convention, Pasadena, Cal., October 13-17, 1924.

the characteristic impedance K and propagation constant Γ, so that the current $I(z)$ and voltage $V(z)$ of the direct wave at a distance z from the terminals are given by[3]

$$\begin{aligned} I(z) &= I_0(z) = J\,e^{-\Gamma z} \\ V(z) &= V_0(z) = K\,J\,e^{-\Gamma z} \end{aligned} \tag{1}$$

The analysis underlying this paper shows, however, that this expression is incomplete and that the actual direct wave is represented by

$$\begin{aligned} I(z) &= I_0(z) + \sum_1^{\infty} i_n(z) \\ V(z) &= V_0(z) + \sum_1^{\infty} v_n(z) \end{aligned} \tag{2}$$

or

$$\begin{aligned} I(z) &= J\,e^{-\Gamma z} + \sum j_n\,e^{-\gamma_n z} \\ V(z) &= K\,J\,e^{-\Gamma z} + \sum k_n\,j_n\,e^{-\gamma_n z} \end{aligned} \tag{3}$$

I_0, V_0 of the preceding formulas are the current and voltage of what will be termed the *Principal Wave* while the summations represent *Complementary Wave.*[4] That is to say, in addition to the wave characterized by the propagation constant Γ and characteristic impedance K, an infinite series of waves of propagation constant γ_n and characteristic impedance k_n ($n = 1, 2 \ldots \infty$) can, and in general do, exist. The character, significance and function of these complementary waves will be considered in more detail subsequently in connection with two simple but representative transmission systems.

Now consider a second case, that of two similar and equal straight parallel wires, so related to the impressed source of energy that equal and opposite currents flow in the two wires. These wires will be assumed to be surrounded by a perfect dielectric. Again, in accordance with the usual transmission theory, propagation is completely determined by the characteristic impedance K and propagation constant Γ, so that

$$\begin{aligned} I(z) &= I_0(z) = J\,e^{-\Gamma z} \\ V(z) &= V_0(z) = K\,J\,e^{-\Gamma z} \end{aligned} \tag{4}$$

The complete wave, however, must in general be represented by the expression

$$\begin{aligned} I(z) &= I_0(z) + \int_0^{\infty} i(z;\mu)\,.\,d\mu \\ V(z) &= V_0(z) + \int_0^{\infty} k(\mu)\,i(z;\mu)\,d\mu \end{aligned} \tag{5}$$

or

$$\begin{aligned} I(z) &= J\,e^{-\Gamma z} + \int_0^{\infty} j(\mu)\,e^{-\gamma(\mu)\,.\,z}\,d\mu \\ V(z) &= K\,J\,e^{-\Gamma z} + \int_0^{\infty} k(\mu)\,j(\mu)\,e^{-\gamma(\mu)z}\,d\mu \end{aligned} \tag{6}$$

The complementary waves in this case are represented by an infinite integral instead of the summation of the preceding case.

The foregoing considerations should present no difficulties to the mathematician; to the engineer, however, their significance may not be quite so clear or so simple. It may be well therefore to pause here, and attempt to give by analogy an idea of the distinction between the principal and the complementary waves, or, otherwise stated, between the particular and the complete solution of the wave equation. Engineers are familiar with the fact that, if a sinusoidal e. m. f. is acting on a circuit, the steady-state formulas for the current are incomplete, and that the complete solution requires the addition of the complementary or characteristic oscillations of the network. Thus if the e. m. f. is $E\,e^{i\omega t}$, the complete expression for the current is[5]

$$I = \frac{E}{Z(i\,\omega)}\,e^{i\omega t} + \sum A_k\,e^{p_k t} \tag{7}$$

where $p_1 \ldots p_n$ are the roots of the equation $Z(p) = 0$. The constants $A_1 \ldots A_n$ of the complementary oscillations are determined by the state of the system when the e. m. f. is impressed or when any change in circuit constants occurs. That is, they must be so chosen as to satisfy the imposed boundary conditions at any reference time $t = 0$. Furthermore, as the time interval which has elapsed since the occurrence of a discontinuity in the applied e. m. f., or in the circuit constants, becomes larger and larger, the complementary oscillations become smaller and smaller, so that after a theoretically very long, but in most practical cases actually very short interval of time, the characteristic oscillations can be ignored and we can write, with negligible error,

$$I = \frac{E}{Z(i\,\omega)}\,e^{i\omega t} \tag{8}$$

Now returning to the case of wave propagation along wires, the spatial boundary conditions at the physical terminals of the system ($z = 0$) or at any point of discontinuity in the line, must be everywhere satisfied, and these boundary conditions can in general be satisfied only by the characteristic or complementary waves. They thus correspond to the complementary oscillations in the network case, while the principal wave corresponds to the forced oscillations, as given by (8).[6] The analogy can be carried still further; just as in the network problem, the complementary oscillations become smaller as the time increases, so in the wave propagation the complementary waves become relatively smaller and smaller as the distance z from the

3. The common factor $e^{i\omega t}$, indicating steady state phenomena of frequency $\omega/2\pi$, will be omitted throughout. It will be understood, however, as a factor in all currents and voltages.

4. It should be clearly understood that the term *Principal Wave* designates the guided wave which alone is recognized in ordinary engineering theory.

5. The expression $Z(i\,\omega)$ indicates the network impedance at frequency $\omega/2\pi$. Thus for a circuit of resistance R and inductance L, $Z(i\,\omega) = R + i\,\omega\,L$.

6. It may be well to point out that explicit consideration is here limited to steady-state phenomena *in time*. The general case involves a four-dimensional boundary value problem.

physical terminals is increased.[7] The analogy is, of course, by no means perfect but is offered with the thought that it may prove helpful to the reader in grasping the significance of the complementary waves and the logical necessity for their existence.

The complete solution of wave propagation along a conducting system requires an entirely different theoretical treatment from that underlying the elementary engineering theory leading to the usual transmission formulas. In fact the assumptions underlying the latter expressly exclude the complementary waves. As is well known, the transmission formulas are derived from the differential equations

$$-\frac{\partial}{\partial z} V = Z_1 I$$
$$-\frac{\partial}{\partial z} I = \frac{1}{Z_2} V \qquad (9)$$

where Z_1 and Z_2 are the series and shunt impedance, per unit length of the line. The solution of these equations gives a propagation constant $\Gamma = \sqrt{Z_1/Z_2}$ and a characteristic impedance $K = \sqrt{Z_1 Z_2}$, so that the wave is simply

$$I(z) = I = A e^{-\Gamma z} + B e^{\Gamma z}$$
$$V(z) = V = K A e^{-\Gamma z} - K B e^{\Gamma z} \qquad (10)$$

In accordance with (**10**), the wave consists of an exponentially propagated direct and a similar reflected wave and these are the complete solution of equations (**9**), and involve only two arbitrary constants of integration A and B to satisfy the boundary conditions at the physical terminals of the line.

The complete solution, on the other hand, is arrived at by starting with Maxwell's equations and building up the general solution from the elementary solutions of the field equation which individually satisfy the geometry and electrical constants of the conducting system. This analysis shows that in addition to the principal wave, corresponding to the wave of engineering theory, there is an infinite number of waves (expressible as an infinite series or an infinite integral, depending on whether the system is radially bounded or unbounded), which individually satisfy Maxwell's equations and the geometry of the conducting system, and which, therefore, can exist independently. The complete solution is, therefore, built up out of all the particular solutions, the unknown constants of integration being theoretically determinate and determinable from the boundary conditions at the physical terminals on the system, and at points of discontinuity. Each wave of current (and voltage) is accompanied by a characteristic field distribution of E and H, and the aggregate field must satisfy the conditions of continuity both at the principal terminals of the system and at points of discontinuity along the line. Thus, at every point of discontinuity, represented say by a change in direction of the line, or by a change in the electrical constants or structure, both direct and reflected complementary waves are called into existence. The complementary waves may either merely rearrange the field or they may abstract from, or contribute energy to, the principal or guided wave. In this way it is possible to account for radiation phenomenon, while recognizing the fact that *the principal wave is not attenuated by radiation.* That is to say, the principal wave is affected by radiation only by losses or gains of energy at the terminals or at points of discontinuity along the line, and not in its mode of propagation.

The actual solution of any specific problem in wave propagation, including the evaluation of the complementary waves, is an extremely difficult boundary-value problem, even in the simplest possible case. If the electric field is specified everywhere over any plane normal to the axis of transmission, the complementary waves are theoretically directly determinable. In most physical problems, however, the determination of the complementary waves involves the solution of an infinite integral equation. Fortunately, at least for simple transmission systems, the significance and general character of the complementary waves, and the important distinctions, both physical and mathematical, between them and the principal wave, can be deduced without a complete solution of the boundary-value problem. This will now be briefly done, without detailed mathematics, for the two simple conducting systems mentioned above.

Submarine Cable. Wire of perfect conductivity, radius a, centered on z axis, surrounded by concentric perfectly conducting cylinder of radius b. Internal and external conductors separated by perfect dielectric.

This system possesses circular symmetry; it will be assumed for the sake of simplicity that the boundary conditions, and hence the complete wave is also symmetrical about the axis of transmission. The assumption of perfect conductivity is made for the sake of simplicity, and does not essentially affect the character of the phenomena or the conclusions arrived at.

Assuming for the moment that the line is infinitely long along the positive Z axis, the complete wave is

$$I = J e^{-\Gamma z} + \Sigma j_n e^{-\gamma_n z}$$
$$V = K J e^{-\Gamma z} + \Sigma k_n j_n e^{-\gamma_n z}$$

The propagation constant and characteristic impedance of the principal waves are then given by

$$\Gamma = i \omega \sqrt{LC} = i \omega / c$$
$$K = \sqrt{L/C} = 2c \,.\, \log(b/a)$$

That is, the principal wave is propagated without attenuation with the velocity of light c, and the value of the characteristic impedance K agrees with that of elementary theory. The principal wave has no components of electric intensity along the axis of transmission Z, and is, therefore, a true plane wave, centered on the axis of transmission, along which it is propagated with the velocity of light.

7. This statement is not perfectly general and exceptions are noted and discussed later.

The propagation constant γ_n ($n = 1, 2, 3 \ldots \infty$) of the complementary waves is given by

$$\gamma_n = \sqrt{h_n^2 - \omega^2/c^2}$$

where h_n is the nth root of the transcendental equation

$$J_0(h\,a)\,K_0(h\,b) - J_0(h\,b)\,K_0(h\,a) = 0$$

J_0, K_0 being the Bessel functions of the 1st and 2nd kind respectively and zeroth order. The roots of this equation have been computed (see Jahnke u. Emde, *Funktionen-tafeln*, pg. 163). The first few roots are approximately

$$(b-a)\,h_1 = 2.40$$
$$(b-a)\,h_2 = 5.52$$
$$(b-a)\,h_3 = 8.65$$
$$\ldots\ldots\ldots\ldots$$
$$(b-a)\,h_n = n\,\pi \quad \text{for large values of } n$$

so that

$$\gamma_1 = \sqrt{\left(\frac{2.40}{b-a}\right)^2 - \left(\frac{\omega}{c}\right)^2}$$

$$\gamma_2 = \sqrt{\left(\frac{5.52}{b-a}\right)^2 - \left(\frac{\omega}{c}\right)^2}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\gamma_n = \sqrt{\left(\frac{n\,\pi}{b-a}\right)^2 - \left(\frac{\omega}{c}\right)^2}$$

For all frequencies and physical dimensions at all likely to be encountered in practise, the term $(\omega/c)^2$ is negligibly small, and, to an exceedingly close approximation

$$\gamma_1 = \frac{2.40}{b-a}$$

$$\gamma_2 = \frac{5.52}{b-a}$$

$$\ldots\ldots$$

$$\gamma_n = \frac{n\,\pi}{b-a} \quad \text{for large values of } n$$

For this case all the complementary waves are attenuated, and the least attenuated complementary wave is reduced by the factor $e^{-2.4}$ at a distance along the axis of transmission equal to the separation between inner and outer conductor. This attenuation is relatively enormous, and explains the fact that at a short distance from the physical terminals of the system, the wave is represented without sensible error, by the principal wave alone. It is theoretically possible, however, to choose a frequency and physical dimensions such that a finite number of complementary waves is unattenuated. In such a case the complete wave is never representable by the principal wave alone, no matter how great the distance from the terminals of the system.

The complementary waves, as distinguished from the principal wave, are not true plane waves. The axial electric intensity of each complementary wave vanishes at the surface of the conductors but in the dielectric between the conductors is, in general, finite. A second outstanding distinction is that the characteristic impedance k_n ($n = 1, 2 \ldots$) is zero. That is to say, the line integral of the radial electric force between the two conductors is zero for each complementary wave.[8]

Since the wave is included between perfectly conducting surfaces, there is, of course, no radiation or dissipation of energy. But since, for the case considered, each complementary wave is attenuated, it follows from energy considerations that the complementary waves convey no energy, all the energy transmission being associated with the principal wave. (This statement is not exact in the case of dissipative wires, where a small amount of energy may be transmitted by the complementary waves). They, therefore, involve only a surging of energy and a rearrangement of the field.

From the formula (2) and (3) for the infinitely long line

$$I(z) = I_0(z) + \sum_1^\infty i_n(z)$$

$$V(z) = V_0(z) + \sum_1^\infty v_n(z)$$

it follows that the ratio of V/I is not a constant, but a function of the distance z from the terminals. Thus

$$V/I = K\,\frac{1 + \Sigma \dfrac{k_n\,j_n}{K\,J}\,e^{-(\gamma_n - \Gamma)z}}{1 + \Sigma \dfrac{j_n}{J}\,e^{-(\gamma_n - \Gamma)z}}$$

The ratio j_n/J is determined by the boundary conditions at the terminals $z = 0$; that is, by the mode and conditions in which energy is impressed on the system. It is theoretically possible to imagine the energy so applied as to make the measured impedance in the neighborhood of $z = 0$ widely different from its ultimate value K. On the other hand, when the applied voltage is directly impressed on the system, it appears that the difference between V/I and K is exceedingly small, and in fact almost immeasurably small by engineering methods and apparatus with physical dimensions and frequencies at all likely to be employed in practice. A formal proof of this important statement is extremely difficult; in fact, it must be, at present, regarded as an induction from the study of special representative cases. The explanation of its truth in ordinary practical cases is as follows: The amplitudes of the complementary waves must be such as to make the field vectors continuous in the dielectric in the plane $z = 0$. Now each

8. This is in consequence of the assumption of perfect conductivity in the two conductors. Actually, of course, the conductors must have some resistance, in which case the characteristic impedance k_n is not exactly zero, but in good conductors is exceedingly small compared with the characteristic impedance K of the principal wave. It may be remarked here that the inclusion of dissipation modifies only slightly the conclusions stated for the ideal case, and this modification is merely quantitative and not qualitative. The ideal case is dealt with purely for the sake of simplicity.

complementary current wave is accompanied by a characteristic field[9] in the dielectric, and this field is relatively exceedingly intense for a given current value, as compared with the corresponding ratio in the principal wave. Consequently, extremely small amplitudes of the complementary current waves are sufficient to produce the necessary field to satisfy the continuity conditions in the dielectric. The statements and explanation, which are extremely important for the engineer, are borne out by experiment, which so far as the writer is aware, have never been refined enough to directly detect the presence of the complementary waves.

So far, we have considered the ideal case of the infinitely long cable, and dealt with the complementary waves occurring at the place where the cable wave is initiated. Direct and reflected complementary waves are set up, however, at every point of discontinuity along the line. For example, consider a cable of two sections, extending from $z = 0$ to $z = z$, and from $z = z$, to $z = \infty$ respectively; and let z_1 be so large that the direct wave in the first cable section is representable from $z = z_1$ by the principal wave alone. Let us assume also that the two-cable sections differ in electrical constants or structure. Then when the direct wave arrives at $z = z_1$, both direct and reflected complementary waves are set up, and the principal direct and reflected waves are not determined with theoretical exactness by the continuity of their current and voltage waves. In fact, this condition, universally employed in engineering calculations, is not theoretically correct, and is only approximately correct because the complementary current and voltage waves are extremely small.

An interesting deduction from the analysis of the ideal cable has to do with energy transmission and its relation to current and voltage. In the case under consideration, when the wires are of perfect conductivity, the transmission of energy occurs entirely in the dielectric and its magnitude and direction are calculable from the Poynting Vector, or the vector product of electric and magnetic intensity. In the case of the principal wave, which is a true plane wave, the energy transmitted per unit time along the axis is equal to $V \cdot I$, which, of course, agrees with the usual engineering formula. In the case of the complementary waves, however, which are not plane waves, V is identically zero. But, as stated above, it is theoretically possible to transmit energy by the complementary waves by a proper choice of frequency. It is, therefore, theoretically possible to transmit energy without any voltage between wires. As a matter of fact, in the actual case of dissipative wires, the energy transmitter by the principal wave is not exactly equal to $V \cdot I \cos\theta$, although the approximation is exceedingly close in all practical cases.

In the usual case where the complementary waves convey little or no energy, the engineer is concerned primarily with the principal waves of current and voltage and, of course, does not want or need to complicate his formulas by explicitly including the complementary waves. They can be omitted and the calculations made in accordance with usual engineering practise, while at the same time correctly taking into account their modifying effect as regards current and voltage by aid of the following propositions:—The effect of the complementary waves, as regards the principal wave of current and voltage, can be correctly accounted for by imagining that at the terminals of the line, and at every point of discontinuity, a T network of appropriate constant is inserted. The propagation and reflection of the principal wave are then calculated in the usual manner without further recognition of the existence of the complementary waves. The constants of the hypothetical network are theoretically determinable from the boundary conditions.

This proposition is extremely important theoretically because it brings out the important fact, that as regards energy transmission, the complementary waves represent merely a terminal and reflection effect. Practically, of course, at ordinary frequencies, the series impedance of the T network is so small, and the shunt impedance is so large, that the effect can be neglected with vanishingly small error.

The case just discussed, that of the ideal cable, is both interesting and instructive, and the deductions made are generally applicable. In view of the fact, however, that the dielectric, which is the seat of the energy transmission, is completely enclosed by a perfectly conducting (and therefore perfectly reflecting) surface, radiation of energy is necessarily excluded. We shall now briefly consider a more practical case where this limitation is removed, namely two similar and equal parallel wires, in which equal and opposite currents flow. Again, purely for the sake of simplicity, the wires will be assumed perfectly conducting. In this case the direct wave is represented by

$$I(z) = J e^{-\Gamma z} + \int_0^\infty j(\mu)\, e^{-\gamma(\mu) z}\, d\mu$$

$$V(z) = K J e^{-\Gamma z} + \int_0^\infty k(\mu)\, j(\mu)\, e^{-\gamma(\mu) z}\, d\mu$$

The principal wave, represented by the term outside the integral is a true plane wave, propagated without attenuation, with the velocity of light ($\Gamma = i\,\omega/c$). Its characteristic impedance K is calculable by usual methods. The complementary waves are now represented by an infinite integral replacing the summation of the preceding example. The function $j(\mu)\, d\mu$ which gives the amplitude of the component of propagation constant $\gamma(\mu)$ is theoretically determinable

9. In the present paper, the problem has been approached from the viewpoint of the current and voltage waves in which the engineer is interested. As a matter of fact, however, the mathematical analysis deals directly with the field in the dielectric.

from the boundary conditions. The propagation constant $\gamma(\mu)$ and characteristic impedance $k(\mu)$ are determined by the frequency and geometry of the system, are continuous functions of the variable μ, and are independent of the boundary conditions. The impedance $k(\mu)$ is, in the usual case, either zero or extremely small compared with K. The propagation constant is given by the formula

$$\gamma(\mu) = \sqrt{\mu^2 - (\omega/c)^2}$$

For values of $\mu < \omega/c$ the propagation constant is a pure imaginary, corresponding to unattenuated transmission of the infinitesimal current wave component $j(\mu)\, d\mu$. It may be shown by mathematical analysis that the energy radiated from the system is entirely associated with that part of the complementary current wave for which $\mu < \omega/c$; that is with the current wave

$$\int_0^{\omega/c} j(\mu)\, e^{-\gamma(\mu)z}\, d\mu$$

and that the radiation of energy can be directly accounted for by this part of the complementary current wave, and its accompanying characteristic electromagnetic field.

At this point we are in a position to explain the anomaly that the radiation from the system can be calculated, to a good approximation, without explicit recognition of the complementary waves. As stated above, in almost any conceivable practical transmission system, the complementary current wave is exceedingly small compared with the principal current wave. At a great distance from the wires, however, the electromagnetic field of the complementary current wave is, in general, large compared with that of the principal wave, and almost entirely determines the direction and character of energy flow. That is to say, while the complementary *current* and *voltage* waves are extremely small compared with the principal current and voltage waves, the electromagnetic fields associated with the latter do not correctly represent the character and direction of energy flow at a great distance from the wires. On the other hand, the radiation field and flow of energy out of the system can be completely calculated, by means of the retarded vector potential,[10] in terms of the currents in the wires. Consequently if, in making this calculation, we neglect the small corrections due to the complementary current wave, the error introduced into the calculated radiation will itself be small. This is the method previously employed by the writer (JOURNAL A. I. E. E., Oct. 1921) in calculating the amount of energy lost by radiation in wire transmission.

This point is so important that it may be well to emphasize it at the risk of repetition. Suppose that we ignored not only the complementary wave but its associated electromagnetic field, and attempted to calculate the direction and character of the energy flow in the field from the characteristic elementary field of the principal wave alone. In the neighborhood of the wires and at some distance from the terminals (or points of discontinuity in the line) the results of such a calculation would not be greatly in error, but at a great distance from the wires the results would be entirely incorrect, and would, in fact, lead to the totally incorrect conclusion that no radiation from the system takes place. On the other hand, if we calculate the field at a great distance from the wires by means of the retarded vector potential of the principal wire current wave, ignoring the complementary wire current wave, this error is avoided and except in very extreme cases the radiation is thereby calculable to a very high degree of approximation.

Except for the phenomena of radiation, briefly discussed above, the significance of the complementary waves in the open wire case, are very closely the same as in the case of the cable. The hypothetical T networks which can be imagined as replacing the effects of the complementary wave, insofar as the principal current and voltage are concerned, are of the same general character except that in certain cases they must include negative resistance elements.

To summarize the preceding, a preliminary account has been given of a mathematical investigation of guided wave transmission, which discloses effects not recognized by the simple transmission theory, and shows the theoretically incomplete character of the latter. In particular, it substantiates the conclusions previously stated by the writer (JOURNAL A. I. E. E., Oct. 1921) that radiation of energy does not involve attenuation of the guided wave, but that the explanation is to be sought in the existence of effects unrecognized by elementary theory. Insofar as immediately practical and useful information is concerned, the present investigation goes to show that the ordinary transmission is not only an extremely serviceable guide, but one of extremely high accuracy. On the other hand, the refined effects and phenomena, disclosed and discussed in the present paper, may well become of practical engineering concern, as the art of wire transmission develops. The writer hopes to publish the detailed mathematical analysis, underlining the present study, in a future paper.

10. See, for example, Lorentz, The Theory of Electrons.

BEST LIGHTED ROAD

One of the most perfectly lighted stretch of automobile road in the world is located upon the Lincoln Highway a few miles south of Chicago. Twenty-eight concrete standards, spaced 250 ft. apart, each carrying a 250-c. p. electric lamp, equipped with a reflector which throws the light evenly upon the road bed but not beyond it, constitute the lighting equipment of this ideal section of the famous highway. During the course of a year these electric lamps are turned on by the master switch a total of 4000 hours and the yearly cost is less than 25 cents per foot of road illuminated.

The Corona as Lightning Arrester

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Review of the Subject.—*Occasional suggestion has been made in recent years that the properties of the high-voltage corona might be utilized as a protection against lightning and other similar types of disturbance on transmission lines. The idea in these suggestions is that since the ionization attending corona renders the air conducting, the excess voltage following the lightning discharge will be relieved or lowered by leakage between lines or to ground. It has been stated that lines operating in the highest range of transmission voltages are more immune from lightning disturbances than those of lower voltage, and that this is due to the fact that they operate nearer to corona-forming voltage, and that abnormal rises of voltage are thus prevented by the relatively low value at which corona forms. This paper aims to present additional evidence that the suggestion mentioned is not only sound but has important possibilities. Experiments are described indicating a relatively simple and inexpensive method of equipping transmission lines to take advantage of the protective properties of the corona, without incurring its disadvantages.*

Conductivity Due to Corona

The conductivity of the air, resulting from corona, constitutes a leakage conductance of the line. This general constant of the electric circuit is usually assumed to be zero in a transmission line, although its presence and importance in telephone circuits is well known and understood. Shunted or leakage conductance increases the attenuation or rate of decay of electric waves or impulses, and if present when a disturbance due to lightning passes over a line, must of necessity tend to retard or smooth it out.

We may estimate the value of the conductance due to corona from Peek's[1] expression for the power loss. The loss increases with the excess of voltage above the critical value and also with the frequency, hence the conductance will also have a wide range of value. As examples, two No. 00 wires, discharging corona at 10 kv. above the critical value, might under ordinary conditions have a corona loss of 2.8 kw. per kilometer, and this is equivalent to a shunted conductance of 0.77×10^{-6} mhos per kilometer. Also, suppose this line to be placed 30 ft. above the earth, that it operates at 50 kv., and that it is arranged, by methods described below, for a critical corona-forming voltage of 55 kv. If this line should suffer a lightning disturbance causing a rise of voltage to a value of 60 kv. above ground, the resulting corona power loss would be about 13.8 kw., equivalent to a conductance of 3.8×10^{-6} mhos per kilometer. Higher values would follow greater rises of voltage, but for an approximate estimate of the value of corona for the attenuation of lightning disturbances, we may assume as an average value of g, the conductance, 10^{-6} mhos per km.

Assuming, as now generally accepted, that a chief danger from lightning disturbances lies in the steepness of wave front associated with high-frequency oscillations or sudden pulses, the question before us is as to the influence of leakage conductance, in the amounts suggested above, on the rate of decay of high-frequency transients on power transmission lines.

The Attenuation Due to Corona

The question of the change in shape of the front of a pulse or wave is one of the attenuation or decay of its component frequencies. In considering the value of corona as a protective device, it is necessary to interpret its functions as closely as possible, in terms of the usual constants of the line, and their occurrence in the general equations of wave propagation. The presence of leakage conductance in certain types of telephone circuits has been known a long time and its influence on speech distortion is well understood. In the analysis of transmission line phenomena, however, leakage conductance has always been considered negligible, and the values of the normal circuit constants to remain the same at all frequencies. It is only recently that Steinmetz[2] has studied the variation of the attenuation constant with the frequency, and proposed an explanation of the known rapid decay of steep wave fronts on transmission lines. He concludes that owing to the skin effect and to electromagnetic and electrostatic radiation, the attenuation constants pertaining to the higher ranges of frequency rise to enormous values, and that these frequencies constituting the steep slopes of wave pulses, are rapidly damped out, thus accounting for the relatively limited distances over which the steep fronts of such pulses persist. The values for the attenuation constant as computed range from 70 at commercial frequencies, through, 287 at 10,000 cycles, to 7×10^6 at 5×10^6 cycles; the enormous values at high frequencies are due principally to the loss of energy radiated into space.

In these estimates of the values of the attenuation constant, the leakage conductance is assumed to be zero. If any is present it must, therefore, still further increase the attenuation, and accordingly tend to slow up all frequencies still more rapidly. Now it happens that the values of the leakage conductance due to corona lead to values of the attenuation constant almost as high as those computed for the higher frequencies as due largely to radiation. Moreover, since the corona attenuation is present at low frequencies, and probably in equal or greater value at high frequencies, it is at once evident, if these estimates and assumptions are correct, that the corona must have the effect of slowing

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up high-frequency and steep wave front transients even more rapidly than as now observed and computed.

To arrive at an estimate as to the influence of corona, we may conveniently follow Steinmetz, using both his examples and his method for determining the progressive alteration of several types of transients but using new values of attenuation constant to include the influence of corona. He considers the alteration by attenuation of three types of disturbance likely to arise from lightning or other similar cause; the quarter-wave oscillation, the periodic rectangular wave, and the flattening of a steep wave front. In each case departure is taken from the summational expression representing the Fourier series and involving the succession of terms of increasing frequency making up the wave or pulse. The influence of the attenuation constant, u_n, appears always as $\epsilon^{-u_n t}$, u_n however taking continually increasing values with increasing frequency. The values of u_n are computed as influenced by unequal current distribution (skin effect), electromagnetic, and electrostatic radiation, but the effect of each is reduced to the equivalent series resistance r, or shunted conductance g, per unit length, for ready adaptation to the well-known general circuit equations, as treated by Steinmetz, through the value

$$u_n = \frac{1}{2}\left(\frac{r}{L} + \frac{g}{C}\right)$$

To include the influence of corona we may add another term to the above expression for u_n, or increase g by 10^{-6} mhos per km., the approximate value of the leakage conductance due to corona. Using the proper values of capacity and conductance we find for the case of two No. 00 wires 6 ft. apart and equipped so as to give a normal corona discharge curve at 40 kv., and undergoing a 60-kv. lightning pulse, a value of u_n, due to corona alone, of 4.1×10^6. And for the same two wires 30 ft. above ground and equipped for corona discharge at 55 kv. between lines, when subject to a pulse of 60 kv. above ground, a value of u_n, 2×10^7. A single No. 00 wire 30 ft. above ground has a critical corona voltage of 83 kv. above neutral; for an excess voltage of 10 kv. at normal frequency, the corona power loss would be 0.33 kw., its leakage conductance 4×10^{-8} mhos, and its capacity to earth 6.7×10^{-14} farads, per km.; indicating a corona attenuation constant of 3×10^5. Thus under conditions quite likely to arise in practise, it is possible to look for an attenuation constant of the order of magnitude 10^6, provided only that provision be made for a normal corona discharge curve beginning a few kilovolts above normal line voltage. A method for doing this is described below.

Now it happens that this value of u_n, 10^6, due to corona, is many times greater than the value as computed on the assumption of no leakage conductance, throughout the entire lower range of frequency, and, in fact, is exceeded by the latter only at frequencies above 2×10^6 cycles. Thus as already stated the attenuation constant at ordinary commercial frequencies, no corona present, is 70, at 1000 cycles, 80, at 10,000 cycles, 287, at 10^5 cycles, 3710, at 10^6 cycles 291,500, and at 2×10^6 cycles 1.16×10^6. The effect then of ordinary corona discharge is to increase the attenuation constant enormously throughout the lower range of frequency and to add substantially to its value in the upper ranges. There is good evidence, therefore, that corona may be expected to slow up and smooth out irregular pulses even more rapidly than the rates computed by Steinmetz for corona-free lines and discussed below.

Steinmetz's assumption that the attenuation constant is rapidly increased at higher frequencies through the phenomena of the electro-magnetic and electrostatic radiation has been seriously questioned.[7] However, the influence of these factors on the values of the total attenuation constant including corona formation is very small.. The values of u_n, as deduced by Steinmetz, are far surpassed by the value on a corona-forming line for all frequencies below 1×10^6 cycles. At 2×10^6 cycles, the Steinmetz value, and that due to the influence of corona alone, are about equal, while for higher frequencies the Steinmetz values become greater than those for corona. If, as claimed, therefore, the Steinmetz assumption as to radiated energy is erroneous, the effect on the conclusions below is to be found only at frequencies above 2×10^6 cycles per second. As the range of frequencies above 2×10^6 cycles plays but a small part in the total ranges of the several types of wave considered below, the conclusions reached would not be as seriously affected.

Question may arise as to the time interval required for the setting in of corona, and its power loss, at high frequencies. There is little available experimental evidence here, but such as there is appears to be in the direction of assisting the attenuation influence of corona. In the lower range of frequency a number of observers[3] has noted a slight decrease in the critical voltage with increasing frequency. Ryan's experiments indicated a marked lowering at 40,000 cycles, and those of Peek[4] that the law of corona power loss holds up to 100,000 cycles.

The Damping Influence of Corona on Lightning Disturbances

In the following, the attenuation, caused by corona, of three types of lightning disturbance on a line consisting of two No. 00 B and S wires, 30 ft. above ground, and 100 km. long, is studied and compared with behavior of the corona-free line. The examples are those of Steinmetz and his ingenious methods of approximation to the true values have been followed, with the exception, however, that the attenuation constants at the various frequencies have been increased so as to include the effect of corona.

Quarter-Wave Oscillation. A particular case of a steep wave front is the rectangular wave resulting from the connection of voltage to a transmission line

open at the far end, or the sudden short-circuit of such a line. In these cases there is the possibility of the natural frequency or quarter-wave length oscillation, with superposed harmonics, of the line against ground. It is found that except for points very near the end of the line where the disturbance arises, the maximum voltage gradient, or steepness of the wave front, at time t, and distance $1 = 3 \times 10^{10}\, t$ is, approximately:

$$G = \frac{E}{l_o} \sum_{0}^{\infty} {}^{n}\, \epsilon^{-u_n t}$$

in which E is the line voltage, l_o the length of the line and u_n the attenuation constant for the frequency $(2\,n + 1)\,f_o$, f_o being the natural frequency of the line.

Table I gives the values of maximum gradient of wave front, in volts per meter, length of wave front in meters, and equivalent frequency, for a 100 km. No. 00 B and S two-wire line 30 ft. above ground with no corona present, and also the values of the same quantities when the line is discharging under corona at a voltage about 10 per cent above the critical value. The rapid fall of the voltage gradient on the wave front, and the consequent lengthening of the wave

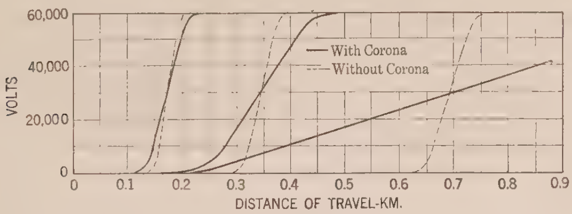

Fig. 1—Attenuation of Quarter Wave Oscillation

front are very noticeable for the corona-forming line. On the latter, the voltage gradient falls to very low value within 1 kilometer of travel, while on the corona-free line the same decrease results only after about 60 kilometers. The rapid decay of the wave is also shown in Fig. 1, in which it is compared with the corona-free line for three distances of travel.

TABLE I
ATTENUATION OF WAVE FRONT OF QUARTER WAVE OSCILLATION ON CORONA FORMING LINE

Time t micro-seconds	Distance of Travel km.	Voltage Gradient Without Corona	Voltage Gradient With Corona	Wavefront Meters Without Corona	Wavefront Meters With Corona	Equiv. Kilocycles Without Corona	Equiv. Kilocycles With Corona
0.575	0.1725	1290	726	73	130	2060	1152
1.15	0.345	967	293	98	323	1540	465
2.3	0.69	630	68	150	1390	1000	106
11.5	3.45	280	0	330	..	450	..
230.0	69.00	58	0	1630	..	92	..

Rectangular Wave. In the case of the pure rectangular wave, made up of all odd harmonics of the fundamental frequency of 60,000 cycles, and represented by

$$e = \frac{4\,E}{\pi} \sum_{0}^{\infty} {}^{n}\, \frac{\epsilon^{-u_n t} \operatorname{Sin}(2\,n + 1)\ \varphi}{(2\,n + 1)}$$

the high values of u_n, due to corona at the lower frequencies, cause a rapid vanishing of terms with increasing values of n and t. This causes the wave to lose its rectangular shape rapidly. As shown in Fig. 2, in less than 1 microsecond, or 300 meters of travel, on a line on which corona is present, the rectangular wave has assumed practically a sine shape, and its amplitude is rapidly decreasing. At 5 microseconds even the fundamental term of the above series is negligible. If the line is not discharging under corona, only the highest frequencies are rapidly damped and the wave is still flat-topped after 40 microseconds or 12 kilo-

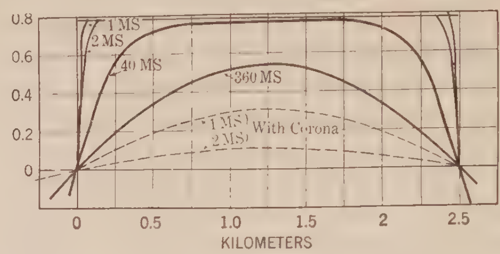

Fig. 2—Attenuation of 60,000-Cycle Rectangular Wave

meters travel, and at 108 km. its amplitude is still higher than that at 1 microsec. (300 meters) on the corona forming line.

Flattening of Steep Wave Fronts. The general expression for the maximum voltage gradient of any steep wave front or pulse of any length is shown to be:

$$G = \frac{2\,E}{3 \times 10^{10}} \int_{-\infty}^{+\infty} \epsilon^{-ut}\, f\, d\,(\log f)$$

in which t is the time since the origin of the pulse, and u, the attenuation constant, a function of f, the frequency. The relative values of this integral for one No. 00 B. and S. wire 30 ft. above ground and for values

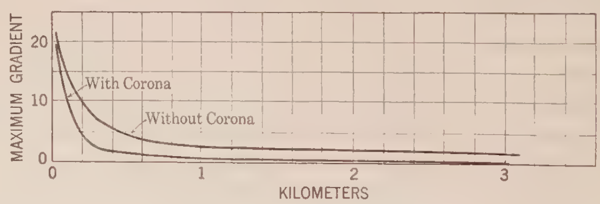

Fig. 3—Flattening of Steep Wave Fronts by Corona

of t from 0.1 to 1000 microseconds, are given in Table II, and the relative values of G as related to the distance of travel of the wave front, shown in Fig. 3, for the cases of corona-free and corona-forming line. The very much more rapid decay of the corona forming line is again clearly evident.

TABLE II
FLATTENING OF STEEP WAVE FRONTS
MAXIMUM VOLTAGE GRADIENT G

Time, seconds	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}
Corona-free line	20.2	6.84	1.86	0.635	0.119
Corona-forming line	18.4	2.47	0	0	0

In each of the foregoing examples a most striking improvement as regards the elements of danger of a lightning disturbance is shown for the corona-forming line. While the figures must be taken as only the roughest of approximations, it is nevertheless believed that they are of the correct order of magnitude. Particularly important is the indication that only relatively short lengths of corona-forming line are necessary, for this minimizes the elements of complication and danger, and reduces costs. In view, therefore, of the apparent advantages to be gained, it remains to examine the problem of a corona-forming line in the light of some of the conditions of normal line construction and operation.

Disadvantages and Difficulties

Looked at from the standpoint of application to existing lines and normal operating conditions, there are several questions which arise and which may constitute serious disadvantages to the use of corona as a protective device. Perhaps the most important is the variation in the value of corona-forming voltage with atmospheric conditions. Corona voltage is raised by an elevation of pressure, and lowered by an elevation of temperature; the influence of temperature is the more important. An annual range of temperature of 60 deg. cent. in any one location is not unusual, and this would mean an elevation of 25 per cent of the cold weather, over the hot-weather, critical voltage. When, however, we note that very short lengths of corona-forming line are indicated as necessary for protection, there would appear to be no difficulty in setting the corona-forming voltage at the value insuring protection under all conditions, and allowing the line to discharge continuously during the periods of high temperature. On an average line, an elevation of voltage of 12½ per cent above the corona-forming value would result in a continuous loss due to corona, of the order of about 1 kw. per mile, so that if the line were set for the average conditions as regards density of the atmosphere, a good measure of protection would result in cold weather, and excellent protection in warm weather, at the expense only of the relatively low value of loss mentioned.

Several writers have attempted to estimate the extent of the protection available through corona, by comparing the probable amount of energy stored in a line at the time of lightning discharge, with the normal rate of power loss from corona. A cloud overhead induces charges on a part of the line. When the cloud discharges, charges are left on the lines immediately raising their potentials. If the rise of voltage exceeds the flashover voltage of the insulators, it is discharged at once; if not, the wave front of voltage advances down the line oscillating back and forth and gradually leaking to ground. If the flash-over voltage of the insulators be taken as the maximum value reached by the lightning voltage, and a length of line of the order of 20 miles be taken, it may be shown that the total amount of energy liberated will be of the order of 2000 or 3000 joules. If this energy is estimated to traverse the line at the velocity of light, the instantaneous values of power are seen to reach very high values, values in fact which are not appreciably lowered by the known rates of dissipation of energy by means of corona. For these reasons some doubt has been expressed as to the value of corona for the purposes in view. If the discussion in the preceding paragraphs of this paper is correct, it is obvious that the entire charge liberated by a lightning discharge cannot proceed down the line with the velocity of light, and it is not so much a question of the total amount of stored energy, as of the steepness of the wave front with which the charge, or voltage, proceeds down the line. Assuming then that the values of stored energy as estimated above are correct, the indications are that the initial steep and dangerous impulse would be quickly retarded, and the total amount of energy would finally dissipate itself by repeated oscillations back and forth along the line, with wave fronts of continually decreasing steepness.

There is also the question of the influence of frequency on the value of corona-forming voltage, as already mentioned. Experimental evidence was cited here, indicating that if frequency does have an influence, it is in the direction of lowering the corona voltage at higher frequencies.

It is quite obvious in connection with all of the above questions that experiment and trial only can answer them. The principal purpose of this paper is to point out the value of shunted conductance as a means of lightning protection, whether or not this conductance be obtained by corona formation, by the use of small line conductors, points on the usual size of conductor, or by any other form of distributed parallel-connected resistance. Furthermore, it is evident that owing to the short lengths of line, and the low values of loss involved, it would be a comparatively easy matter to make a test of the use of corona as a protective device-

Artificial Corona for Existing Lines

Examination of the relation between voltage, size of wire, and spacing for corona formation, shows at once that within the range of practise, only those lines operating at very high voltages and in high altitudes approach in any way nearly the critical corona-forming condition. Usually the corona-forming voltage is from two to three times the normal operating value. In order, therefore, to bring such lines to a corona-forming voltage differing by only a small amount from the operating value, it is necessary either to modify the spacing or to change the size of the conductor. For most values of transmission voltage and size of conductor, the spacing necessary for corona formation is so short as to constitute serious danger of the swinging together of the wires in the spans, or of flash-over. The reduction of the size

of conductor is the more effective means of lowering the normal corona voltage on existing lines. For example, on a line of 1.6 cm. diameter, aluminum cables, with 9 ft. (274 cm.) spacing, reduction of the diameter of the cable one-half value, would result in a reduction of the corona-forming voltage of 33 per cent. A still further reduction in size of the conductor, therefore, would often be necessary in order to produce corona in accordance with the laws for round conductors. Such reductions in diameter would be possible in some instances, by the use of copper clad steel or other conductors of high tensile strength. It is probable, however, that this method of reducing the corona voltage would not be attractive to the average line superintendent. For these reasons it has appeared worthwhile to investigate the possibility of equipping existing lines of standard spacing, with some form of point or stud of such design that the line would give a corona discharge curve equal to, or better than, the normal corona power loss curve, at a voltage as nearly as desired to the normal operating value, and which, in addition, might be applied to the line with relatively little difficulty and expense.

No priority is claimed for this idea, except, perhaps, as regards this country. The power of point discharge for relieving high voltage has long been known. In particular, experiments with short barbed wire lines have been performed by R. Nagel[5] in Germany, who states that two power companies have announced intention to install experimental stretches of barbed wire as lightning protection. However, no notice of this work appears to have been taken in this country, and transmission engineers have not been impressed with the value of the suggestion of corona protection. These facts in large measure prompted the present work.

The experiments of Nagel are especially worth noting, as they give direct evidence of the value of corona or point discharge in reducing high voltage line pulses. He worked with two out-of-doors lines each 250 ft. long. One line consisted of smooth wires, and the other of commercial barbed wire, both of iron. The barbed wire line showed point discharge beginning at 30 kv. Each wire of each line was equipped with a reactance coil at the far end, and across these coils spark gaps were placed. Spark gaps were also placed across the two wires of each line. Electrostatic impulses of 40 kv. were sent at rapid intervals into each of the two lines. The voltage rises at the end of the line between wires was measured by the gaps between wires, and the steepness of the wave by the gaps across the reactances. The barbed wire line showed much lower voltages and flatter waves, the maximum gap lengths for discharge being from 30 per cent to 60 per cent of those for the smooth wires.

Barbed wire, while eminently suitable for such initial experiments, is probably not the best type of discharge conductor. Better results are likely with other and more regular shapes of discharge point. Moreover, the suggestion to replace a section of transmission line with a length of barbed wire is so unattractive that it would probably be refused at once by most transmission engineers. The following experiments then were undertaken with the aim of devising a simple form of stud or clip which may be readily applied to existing lines, which may be so designed as to discharge at any desired value of voltage, and give a discharge power curve as steep or steeper than the normal corona loss curve.

The Experiments

The method of studying the relative corona conductivities of different forms of discharge points is indicated in Fig. 4. A is the conductor to be studied, B a surrounding metal cylinder 30.5 cm. in diameter, and 178 cm. long. This cylinder is perforated with a large number of 1.6-cm. diameter holes, over the whole surface of a central region 76-cm. axial length. Immediately outside this central perforated section, and

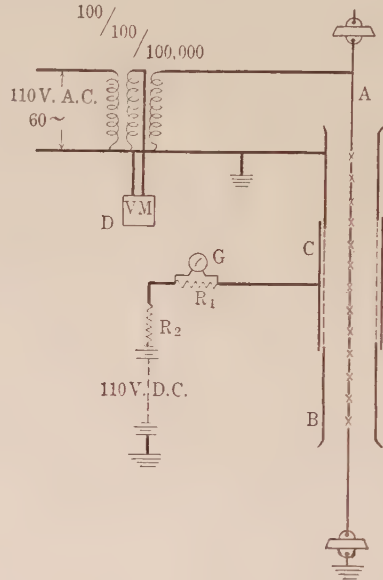

Fig. 4—Diagram of Connections, Conductivity Due to Corona

separated from the outer wall of the cylinder B, is an outer surrounding cylinder of sheet metal, C. This outer cylinder C, well insulated from B, is connected to ground through the resistances R_1 and R_2 and a source of continuous voltage, usually 110 volts. A sensitive galvanometer G is connected across the terminals of the resistance R_1. Cylinder B is connected to ground, and the galvanometer, therefore, indicates the conductivity of the air layer between cylinders B and C. This conductivity sets in as soon as corona appears on the central conductor A, due to the elevation of voltage by the transformer T, the value of voltage being read by the voltmeter D connected to a tertiary coil of the transformer. This is a very simple and convenient method of studying the relative conductivity of different types of corona-forming conductor. It has been described in detail in the author's papers on the corona voltmeter.

As typical of the types of discharge curves to be observed with this equipment, see Fig. 5. The two curves C are given by a nickel plated steel rod with carefully smoothed surfaces, as used in the corona voltmeter[6]. These curves show clearly the sharply marked critical corona voltage, the absence of conductivity below the critical voltage, and the steep ascent of the discharge curve. Curves A and B were taken on a 1.58-cm.

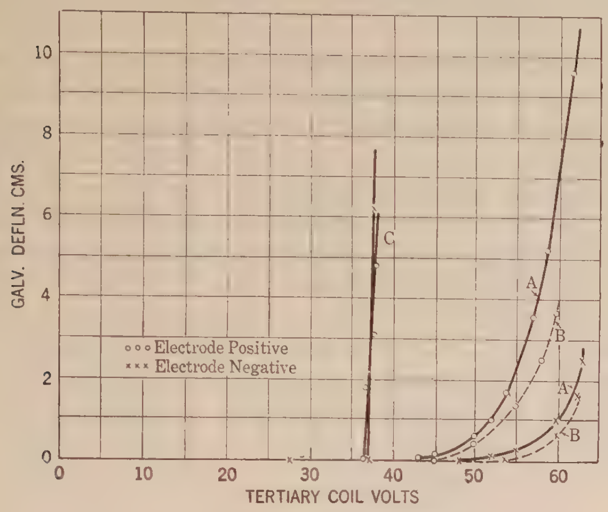

FIG. 5—CORONA DISCHARGE
A. Al. Cable, 19-Strand 5/8 In. Diam. New
B. " " " " " " Weathered
C. Nickel-Plated Steel Rod, 0.188 In. Diam.

diameter, 19-strand aluminum cable; A in the fresh state as taken from the reel, and B after operation for a number of years on the transmission lines of the Pennsylvania Water and Power Company. Two curves are given in each case showing the galvanometer deflections with the electrode C positive and negative. The curves with positive electrode begin earlier and rise more rapidly. This is due to the greater velocity of the negative ions and indicates that for experiments of the present type, the electrode C should be charged with positive potential as being most sensitive to the beginnings of corona. The slightly lower critical voltage of the new cable is probably explained by the fact that its outer layer of strands was not tightly in place. The pitch of the spiral of the weathered cable was nearly twice that of the new, and all the strands of the former were snugly in place.

The Pennsylvania Water and Power Company's lines operate at 70 kv. three phase, 25 cycles, and the samples of cable were kindly furnished by the officials of that Company. This cable was, therefore, taken as a convenient example for a study of possible methods of altering its normal corona discharge curve. The discharge curve of Fig. 5 indicates that this line is operating at a voltage somewhat less than one-half the value of that at which corona would form under normal conditions. The experiments were, therefore, directed toward the development of a suitable point or stud on this cable which would give a discharge curve starting in the neighborhood of 22 volts (tertiary coil) and which should rise from that value as sharply as possible.

The properties of commercial forms of barbed wire were first studied. Six different types were investigated, consisting of twisted pairs of various forms of round and square wires, with points at intervals of from 7½ cm. to 15 cm. The points in all cases were about 1.25 cm. radial length, with jagged points resulting from ordinary cutting processes. The curves of three of these wires are shown in Fig. 6 and are typical of them all. The curves indicate, especially that of sample 3, that barbed wire may be constructed so as to give a fairly steep curve of discharge. All of the types of barbed wire investigated, however, have the disadvantage that their discharge curves all begin at about the same value of voltage and that they are, therefore, not readily susceptible to selection for a specific value of voltage. Moreover, the value of the voltage of initial discharge is

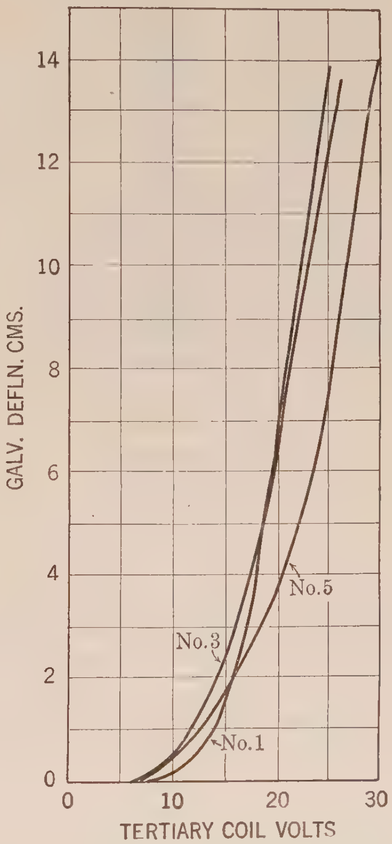

FIG. 6—DISCHARGE CURVES. COMMERCIAL BARBED WIRE
No. 1. Four 5/8-In. Points 3-In. Spacing
No. 3. Four 5/8-In. " 6 3/8-In. "
No. 5. Two 5/16-In. " 5 1/2-In. "

very low, being, for the case of the line in question, about 25 per cent of the value of the normal operating voltage.

The influence of the number and the spacing of the points on ordinary barbed wire was also studied. A number of special samples was constructed, consisting of two 10 B. and S. copper wires twisted together and with points ½ inch long placed in pairs at different distances of separation. The points were those result-

ing from the cutting of the wire with pliers. The curves of Fig. 7 show some of the results. Curve No. 0 shows the discharge of the twisted pair without any points; No. 1 with points spaced at 25 cm.; No. 2, at 12½ cm., etc. It will be noted that the effect of increasing density of points, *i. e.*, the number of points per unit length, is to increase the steepness of the discharge curve up to a certain point. In the present case the spacing of 3½ cm. shows the maximum and steepest discharge curve. A closer spacing as shown by curve 5 evidently has the

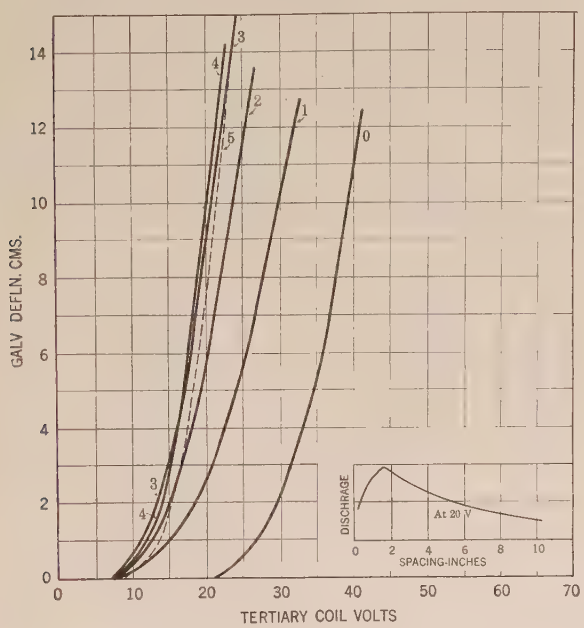

Fig. 7—Influence of Number of Points on Discharge Curve, Uniform Spacing

0	No Points	
1	Spacing 25	Cm.
2	" 12.5	"
3	" 6.25	"
4	" 3.1	"
5	" 1.75	"

effect of reducing the electric intensity at the ends of the points, due to their mutual electrostatic influence. The small inset curve shows the variation of the discharge with the density of points, for a particular value of voltage. The influence of point spacing is also shown in the curves of Fig. 6 in which curve No. 3 with a spacing of points twice that of curve No. 1, nevertheless shows a steeper gradient. The curves of Fig. 7 also show the disadvantage of barbed wire mentioned above, that the discharge begins at a very low value of voltage, and is not susceptible to a variation of critical value.

A large number of different types of discharge point was tried with the 19-strand aluminum cable. In one form narrow bands of sheet iron or aluminum were clamped around the cable with points cut in the metal and bent outward. Points of this character having angles of from 15 deg. to 30 deg. give discharge curves similar to those of barbed wire; that is, they begin from low values of voltage. For a point cut square on the end, the result is only slightly better than that for sharp points. Conical bosses stamped into sheet metal result in higher value of critical voltage, but show discharge curves with a very slow rise.

Some of the results of these experiments are shown in Fig. 8. Curve No. 1 is that pertaining to two 30 deg. sheet steel points 1.25 cm. long, projecting radially at opposite ends of a diameter. Curve No. 2 is that of two 0.32-cm. diameter brass studs 1.25 cm. long, also at opposite ends of a diameter. Curve No. 3 is that resulting from wrapping around the cable in spiral form a No. 8 B. and S. copper wire at the same pitch as that of the strands of the cable, but in opposite direction. Curve 4 is that of the bare aluminum cable. Curve No. 1 for sheet steel points is not suitable for reasons already mentioned. Curve No. 3 is the steepest curve observed throughout the experiments and, therefore, appears to have marked advantages. However, it should be noted that this curve has a critical value of voltage about the same as that pertaining to the bare cable. It is possible that a lower value might be obtained by the selection of a different size of wire, or perhaps a ribbon of special type of cross-section. Since, however, the application

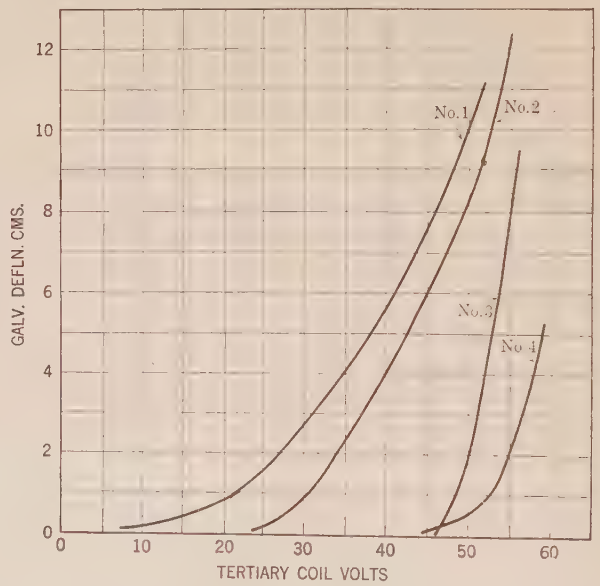

Fig. 8—5/8-In. 19-Strand Cable. Relative Discharge Curves

No. 1. Two Sheet Steel Pts. (30 Deg.) 1.25 Cm. Long
No. 2. Two Brass Studs, 0.32-Cm. Diam., 1.25 Cm. Long
No. 3. No. 8 Wire Spiralled on Cable
No. 4. Bare Cable

of such a spiral or ribbon to existing lines would be troublesome, if not thoroughly impracticable, experiments were not carried further in this direction.

The studs used for Fig. 2 were the only simple and convenient method encountered in which the point of initial discharge could be readily controlled. These studs were turned from brass rod and were of uniform cross-section throughout their length and their ends were rounded to hemispherical shape. The length of stud, diameter, and the radius of curvature of the end,

determine the initial value of discharge voltage; the spacing or linear density of the points along the cable determines the steepness of ascent of the discharge curve. A number of studs of this type were tried and the dimensions given are those selected for a curve starting at about 20 volts (tertiary). The curves of Fig. 9 show the influence of the number of points in increasing the steepness of the discharge curve, and that a 15-cm. spacing gives a discharge curve somewhat steeper than that of the bare cable. A closer spacing might give an even steeper curve, but the gain would be small as compared to the number added. For these reasons it is concluded that the corona-forming voltage of any existing line may be adjusted to any value below that pertaining to the bare cable, by mounting on it in pairs radially projecting studs at a spacing between pairs of about 15 cm. The studs should be of uniform circular cross section with rounded ends. The dimen-

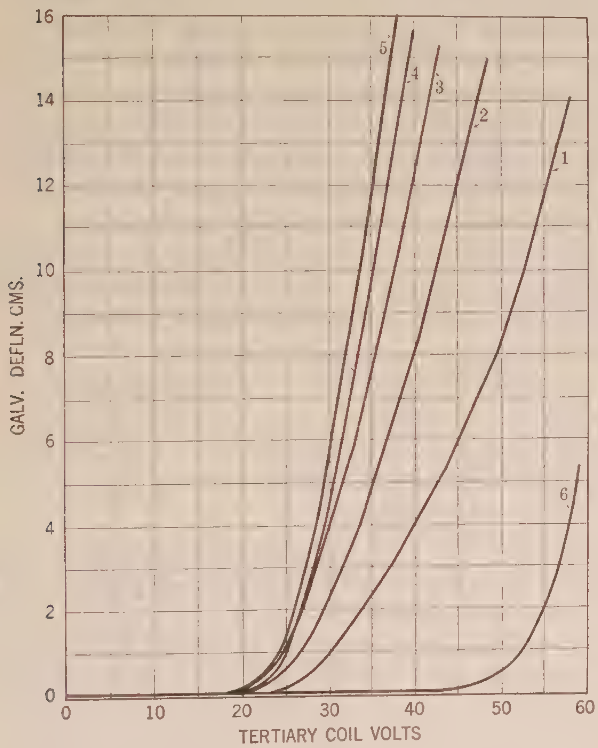

Fig. 9—0.5 In. by 0.125 In. Studs on 0.625 In. Diam. 19-Strand Cable

No. 1. Single Pair
No. 2. 2 Pairs 10-In. Spacing
No. 3. 3 " 5-In. "
No. 4. 4 " 6-In. "
No. 5. 8 " 6-In. "
No. 6. Bare Cable

sions of the studs will determine the voltage of initial discharge, and they can be determined most readily for each new case, by the simple experimental method described above.

A simple and effective method for mounting the points on the cable, is shown in Fig. 10. The brass studs have thin flat heads, somewhat in the manner of rivets. The studs are placed, points outward, through holes in the ends of a thin but stiff spring clip, which is then slipped over the cable. The clip embraces more than half the circumference of the cable, and the two studs are thus a little nearer together, on the open side of the clip, than one half the circumference. By this means the heads of the studs grip the strands of the cable, resulting in a firm attachment of spring clip and studs.

Experiments to test the value of the suggestions

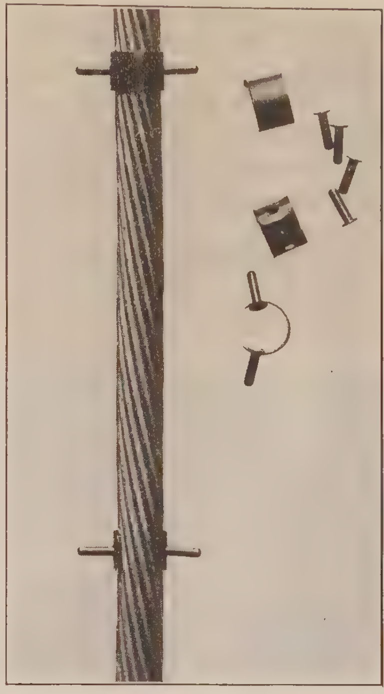

Fig. 10—Corona Discharge Clips on 5/8-In. Cable

above should not be either difficult or expensive. Definite conclusions should be possible from the equipment with suitable studs of say two terminal miles of one of two parallel lines. Comparative observation of the two lines over long periods should afford some evidence, and earlier conclusions would be possible by the use of artificial high-frequency disturbances and suitable means of studying their effects at the protected end of the line.

The author gratefully acknowledges the assistance of Mr. N. Inouye throughout the experiments.

Conclusions

1. The conducitivity resulting from corona on transmission lines is sufficiently high to cause large values of attenuation constant, and the value of corona as a protection against high-frequency and steep wave fronts resulting from lightning and other causes is pointed out.

2. It is indicated that only short lengths of corona-forming line, say one or two miles, are necessary for the full measure of such protection.

3. To take advantage of this method of protection, the corona-forming voltage should be slightly above the operating value. On existing lines this may be

accomplished by reducing the spacing and size of conductor, resulting in uniform corona, or, when this is objectionable, by equipping the conductors with suitable discharging points.

4. The relative discharge values of various types of point are studied experimentally. A simple form of spring clip and stud is proposed, which gives a discharge equivalent to that from corona, and which may be readily mounted on a transmission line conductor.

5. The method has some disadvantages, and its predicted value depends on several assumptions requiring proof. In view of its simplicity and the short lengths of line involved, experiments on the scale of practise should be not only practicable, but attractive, in view of the high degree of protection promised.

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CORRESPONDENCE

To the Editor:

In the January 1924 issue of the Journal, Mr. R. H. Marvin described a temperature and pressure correction chart for the sphere gap. It would appear that considerable calculation could be avoided and at the same time accurate results could be obtained, if the chart were arranged to give the relative air density instead of the correction factor. The correction factors, for a wide range of relative air densities for four standard sizes of sphere gaps, are given in the 1922 A. I. E. E. Rules, Table 205, page 23: curves may readily be plotted from the data in the table. In order to find a correction factor, the procedure would be (1) to read the relative air density from the chart at the given temperature and pressure and (2) to read the corresponding correction factor from the curve for the proper sphere gap. Neither of the two steps presents any real difficulties, as the chart is easy to use, while the spread of the correction factor curves is small for the data given in the table; particularly in the range of relative air densities from 0.80 to 1.10. A tabulation of data used in a chart covering a range of relative air densities from 0.80 to 1.10 is given herewith: in addition to these data, it is necessary to obtain the logarithms of several values of the relative air density from a table of logarithms. The tabulation and the chart are based on the formula:

$$\text{Log}\quad D = \text{Log}\, 9.96\, B - \text{Log}\, (273 + T)$$

where D = relative air density
B = barometer pressure in inches
T = temperature in degrees Centigrade
The logarithms are to the base 10.

B Barometer Pressure Inches	(a) Log $9.96\,B$	T Temperature Degrees Cent.	(b) Log $(273 + T)$	(c) Log D = (a) + (b)	D Relative Air Density
31	2.48962	0	2.43616	0.05346	1.1310
30	2.47538	10	2.45179	0.02359	1.0558
29.92	2.47422	20	2.46687	0.00735	1.0171
29	2.46066	25	2.47422	−0.01356	0.96926
28	2.44542	30	2.48144	−0.03602	0.92040
27	2.42962	40	2.49554	−0.06592	0.85917
26	2.41323	50	2.50920	−0.09597	0.80173

In the chart, the points plotted from the values in the (a) column are labelled with the corresponding values in the B column, while the points plotted from the values in the (b) column are labelled with the corresponding values in the T column. In the chart, each interval corresponding to one inch in B is divided into ten equal parts, while each interval corresponding to 10 degrees in T is also divided into ten equal parts: sufficient points are given to make the error negligible, due to the difference between the equal divisions in the intervals and the proper logarithmic divisions.

A convenient scale is: 1.0 millimeter = 0.0005 logarithm for columns (a) and (b). The lengths of the corresponding lines in the chart then become:

$$\text{(a)}\quad \frac{2.48962 - 2.41323}{0.0005} = 152.8 \text{ millimeters}$$

$$\text{(b)}\quad \frac{2.43616 - 2.50920}{0.0005} = 146.1 \text{ millimeters}$$

The (a) and (b) lines may be placed 120 millimeters apart, which would bring the center line corresponding to (c), 60 millimeters from either (a) or (b). The scale for column (c) must be 1.0 millimeter = 0.0010 logarithm (twice the value for (a) and (b)), since the scale used for (a) and (b) would give points for (c) corresponding to the square root of D. The starting points for the (a) and (b) scales may be opposite each other at 26 and 50 respectively, while the reference point on the (c) scale is at 1.00, where a line joining 29.92 on the (a) scale and 25 on the (b) scale crosses the (c) scale. Points are plotted on the (c) scale for the logarithms of 1.02, 1.04, 0.98, 0.96, etc. (log 1.0 is zero) and labelled with the corresponding numbers. If the intervals between these points are divided into only two equal parts, an accuracy of about 0.2 per cent may be obtained by estimating the intervening values. When completed, the accuracy of the chart may be checked by comparing the relative air densities obtained for the values of B and T given in the tabulation, with the corresponding values in column D.

C. T. Weller

Large Steam Turbine Generators

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Review of the Subject.—*The authors discuss the manufacture of large steam turbine-driven generators touching on what is considered the best practises of the present day. A description of a 62,500-kv-a. 60-cycle generator is included together with test data. The fact is brought out that even on the largest generators yet built, moderate temperatures may be expected. The losses and ventilation problems involved in this type of apparatus are discussed, and predictions made as to the probable sizes at given speeds which may be expected in the future.*

* * * * *

THE power companies that generate and distribute power in the largest amounts have continually asked for larger and larger steam turbine units, with the result that 30,000-kw. units have become quite numerous. The design of the turbine and of the generator at every step to larger sizes involves distinct problems that in nearly all cases are worked out by two distinct groups of engineers. These two groups are in continual competition as to which can produce the larger machine at any given speed,—steam turbine or electric generator.

It is gratifying to the designer, the manufacturer and the user of the largest steam turbine generators that have been built, to find that they prove in service as good in practically every respect as the best of the older and much smaller units. The extremely large generators at the present time are possible, by reason of improvements in materials in both their electrical and mechanical properties, and improvements in details of construction that have in view the protection of the insulation against small movements that are produced by mechanical stresses and by changing temperatures. Progress is dependent, to a large extent, upon research work, improvements in construction and the development of better materials for any given purpose; for example, retaining bands of greater strength to hold the field coils in place at heads of the rotor, or steel laminations for stator cores of better characteristics in the matter of permeability or hysteresis and eddy current losses. Improvements in the mechanical strength of materials in the rotor permit of higher peripheral velocities. At the present time good practise is limited to speeds of about 25,000 feet per minute. Any discovery or development that would permit of an increase of 10 per cent would at once allow the possible size of unit to be increased approximately 33 per cent, since the possible largest size varies approximately as the cube of the peripheral speed.

Installations of several of the largest steam turbine-driven generators built in America have been made during the past year. They are 6-pole 62,500-kv-a. 0.8 power factor, 1200-rev. per min. self-ventilated units. The first of these put into operation is in the Hudson Avenue Power House of the Brooklyn Edison Company—see Fig. 1. Some idea of the size of these units may be obtained from the following weights: rotor 205,000 lb.; stator 205,000 lb.; shields, etc., 25,000 lb.; total, not including base, pedestals or bearings, 435,000 lb. There are some 41,250 lb. of copper in the machine. The stator has 37.6 miles of insulated wire, and the rotor 4.5 miles.

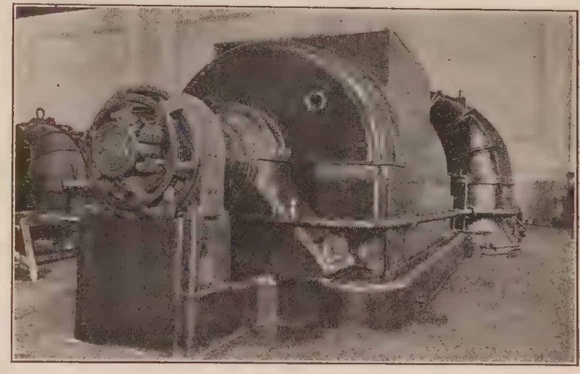

Fig. 1—62,500-Kv-a., 60-Cycle, 1200 Rev., 80 Per Cent Power Factor, 13,800-Volt Generator in Hudson Avenue Power House of Brooklyn Edison Company

Rotor

The rotors of the largest generators consist of steel forgings, many of them of a single forging, which serves as a through shaft with journals for the bearings, and machined to receive coupling at one end for connection to steam turbine, and at the other end for connection of direct connected exciter, if one is supplied; the main body of the forging serving as the field part of the magnetic circuit and machined to receive the field windings. The rotor of the 62,500-kv-a. 1200-rev. per min. generator consists of three forgings, the middle one a hollow cylinder.

One of the most interesting processes of machining in the shop is the milling of the slots in these large rotors. Fig. 2 shows two cutters at work at diametrically opposite points on a 4-pole rotor. A great amount of material must be removed by these cutters, especially in the case of a rotor for a 6-pole machine of as great as 62,500 kv-a. capacity. The cutters employed for this work have been developed to their present degree of perfection by little inventions from time to time during

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the past few years, such as methods of securing cutter teeth in place and removing them quickly. At the same time great improvements have been made in the treatment of the steel used in the teeth. The result of all this improvement is that the quantity of material now removed in a given time is practically twice that of a few years ago; at the same time the cutters themselves

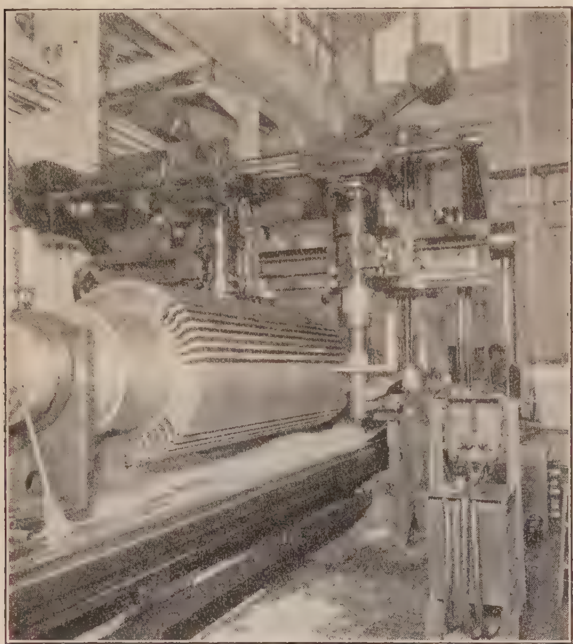

Fig. 2—Milling Two Coil Slots at Once, 7 In. Deep by 1.375 In. Wide, in 4-Pole Rotor for 35,300 Kv-a. Generator. The Cutter Concealed from View by the Rotor Body is Milling the Slot Diametrically Opposite

Fig. 3—Rotor Retaining Ring for 62,500-Kv-a., 1200-Rev. per Min. Generator, Ready for Expanding by Heat and Shrinking On

require much less attention, the cutter teeth remaining in fit condition a much longer time before sharpening is necessary.

The forming up of the field coils for such extremely large machines has been made possible by the development of special machines for winding the coils. The winding machine not only bends to a small radius the heavy copper strip on edge, but changes the pitch every turn, since the winding must be assembled turn by turn in radial slots.

The method of securing the windings against centrifugal force by metallic wedges driven into the dovetail grooves in the sides of the slot throughout the body as well as the retaining rings used at the heads of the rotor, remains practically the same as for many years but continual improvements have been made in small details. At the present time steel wedges are employed throughout the slot portion. These are of magnetic steel in the slots immediately adjacent to the pole center and of non-magnetic to prevent magnetic leakage in the outer slots of every pole. The retaining bands regularly used in these machines are of nickel steel, or a similar steel alloy, and are, consequently, of

Fig. 4—Rotor of 62,500-Kv-a. 13,800-Volt, 60-Cycle, 1200 Rev. per Min. Steam Turbine Generator

35 ft. long, 205,000 pounds' weight, completely wound and supported from crane for transit through building to receive binding bands in shop where both stators and rotors are wound.

magnetic material. It would be desirable to have these retaining bands of non-magnetic material, if workable material were available that had sufficient strength. Fig. 3 shows the retaining ring or binding band for one end of one of the 62,500-kv-a. rotors. A good idea of the size of this ring can be formed from the fact that three men of average size are standing side by side inside the ring.

Some of the most important problems that have had to be worked out in connection with these machines is the securing in place of the insulation on the ends of the several field coils, as also the securing in place of the completely insulated coil so that the immense stresses of centrifugal force, as well as expansions and contractions of changing temperature will not injure the insulation or disturb the balance of the rotor. As shown in Fig. 5, the present method employed is the encasing of the insulated coils in metallic saddles.

These are made of aluminum. The blocking between coils is of the same material.

Stator

Fig. 6 shows a view of the frame of one of these machines. It is of the well-known fabricated structure,

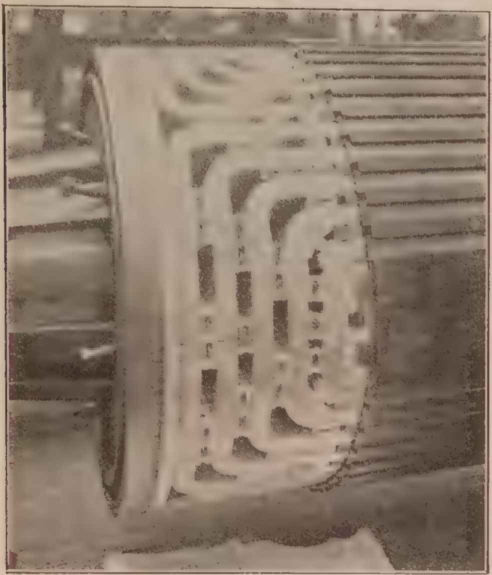

Fig. 5—View of End of Rotor of a 35,300-Kv-a. 1500 Rev. per Min. Steam Turbine Generator Rotor

Ready for receiving retaining ring, showing field coils encased in aluminum saddles and mechanically supported by specially designed aluminum blocks.

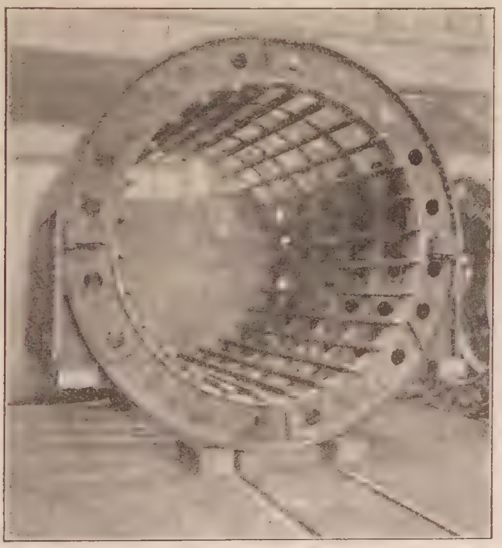

Fig. 6—Stator Complete, Ready for Stacking of Armature Core of 62,500-Kv-a., 1200-Rev. per Min. Generator

Showing multiplicity of ring castings tied together by boiler plate riveted to the outer periphery and by steel bars bolted to inner periphery that carry dovetail slots for assembly of laminations and threads at ends for assembly of clamping flanges and nuts.

which has been successfully used for a number of years. As clearly shown, the frame consists of six annular cast *I*-sections, which are held at the outer periphery by heavy boiler plate riveted to the flanges of the sections. This results in an unusually light and strong structure. There are twenty-eight rectangular steel bars bolted to the inner periphery of the *I*-sections. These bars serve a triple purpose; first, they add stiffness to the frame; second, they are slotted so as to receive the dovetail keys and punchings; third, the ends are turned down and threaded so they act as clamping bolts for the flanges which restrain the core at each end of the machine.

As to the winding, there are 126 coils, each having three turns of 85.8 per cent pitch. Each turn consists of sixteen asbestos insulated strands having a section of 0.21 in. by 0.085 in. Connected with six circuits per phase, a current density of 1521 amperes per square inch is obtained. These six circuits per phase are separated into two groups of three circuits each. Inasmuch as the insulation of the winding and connections was guaranteed to withstand a high potential test of 40,000 volts for one minute, extra insulation was applied. The total thickness of insulation from copper to slot wall is 0.280 in. This high potential test at 60 cycles was successfully applied, using a 300-kw. transformer and a separate generator for controlling the voltage. The charging current measured in the grounded side of the 40,000-volt circuit was 5.6 amperes for each of the three phases. This corresponds to 224 kv-a.

The coils and turns are insulated by hand with mica tape throughout their entire length. High thermal conductivity is secured and compact solid insulation is obtained free from entrapped air by subjecting the insulated hot coils more than once for many hours to a vacuum treatment followed each time by injections of a hot sealing compound under pressure.

Nine insulated leads, instead of the usual six, are brought out from the armature connections through the terminal board. Of the three leads per phase, one goes to neutral and one to each of the two groups of circuits mentioned above. This arrangement permits the insertion of the current transformers used with the balanced relay system of protection for generators, also the insertion of a differential current transformer at the line end of each phase of the winding. Normally, current passes equally through the double primary coils of the differential current transformer from the two halves of the divided generator phase winding. Any unbalance of the currents in the two groups of circuits per phase produces currents in the secondary which can be made to trip out the generator at any desired setting in this secondary circuit.

Temperatures and Methods of Determining Same

Searching tests have been made in the shops as well as on generators in commercial service to determine:

1—maximum observed temperature rise on the bare copper of the stator windings:

2—maximum observed temperature rise as commercially measured (between upper and lower coils in the slot) by

(a) 20 in. long, $\frac{1}{8}$ in. wide resistance temperature detectors;

(b) 10 in. long, $\frac{1}{4}$ in. wide resistance temperature detectors;

(c) thermo-couple;

3—differences in temperature at different locations longitudinally in the slot of the commercially embedded detector;

More of these tests have been made on the 35,300-kv-a. 85 per cent power factor (30,000 kw.) generators of various voltages than on any other size. The most recent of these tests was on 13,200-volt machines, when, fortunately, a pair of them came through the shops at the same time and it was possible to run them at full load, zero power factor. Information gleaned from the data obtained, indicates,—

1—that on machines from 12,000 to 14,000 volts, the temperature of the bare copper is approximately 15 deg. greater than the temperature determined by the 20 in. long detector, as located between top and bottom coils in commercial machines, when the latter is from 55 deg. to 60 deg. above temperature of ingoing air;

2—temperatures determined by resistance detector and thermo-couple on bare copper are approximately identical. Temperatures determined by the 20 in. long detector, as located in commercial machines, is approximately the same as determined by thermo-couple;

3—the temperatures at the half-way location in slot are approximately 2 deg. lower than at the quarter-way, which indicates a trifle better ventilation at the half-way.

The actual temperature rises for these 13,200-volt generators, with full-load current, were 48 deg. cent., as determined by 20 in. resistance temperature detector in stator slot, and 72 deg. cent. in rotor winding, as determined by resistance when operating with leading current and, consequently, greater excitation than required for 85 per cent power factor, full load output.

Tests on 62,500-kv-a. Generator

The results of the tests made under actual load on the 62,500-kv-a. generator of the Brooklyn Edison Company are here given in the form of curves:

Fig. 7 shows generator under test equipped with a tall stack for the purpose of determining the quantity of air flowing through the machine. The tests consisted in a series of runs following one upon the other until constant temperature was attained; 1st, at normal speed without excitation; 2nd—at normal speed, no-load, 13,800 volts (the rated voltage); 3rd, at $\frac{1}{4}$ load; 4th, at $\frac{1}{2}$ load; 5th, at $\frac{3}{4}$ load and 6th, at full load. Owing to the conditions of the system into which the generator was feeding, the potential at generator terminals increased with load and attained 14,350 volts at the full 62,500 kv-a. The power factor was slightly less than 80 per cent.

The losses were determined from the quantity of air and the temperature rise of the air at the various conditions. The quantity of air was 112,500 cubic feet per minute.

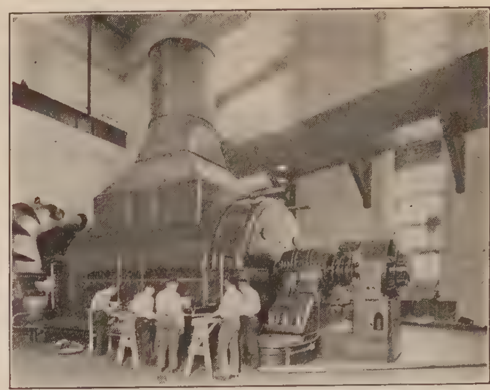

Fig. 7—62,500-Kv-a. 1200-Rev. Generator Brooklyn Edison Company as Equipped with Tall Stock for Measuring Quantity of Cooling Air during the Tests

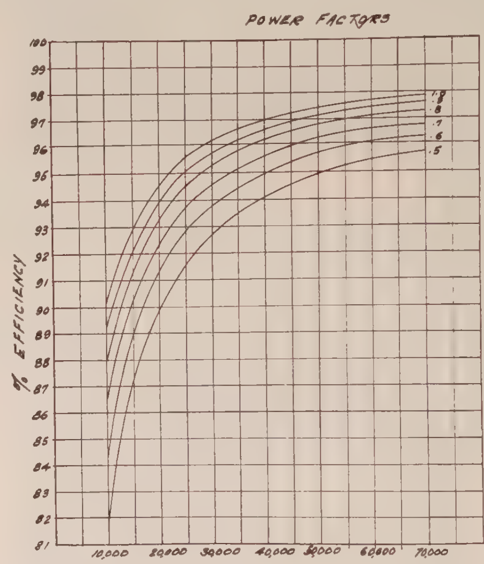

Fig. 8—Efficiency Curves Based upon the Actual Losses as Determined by Tests on 62,500-Kv-a. 13,800-Volt, 1200 Rev. Generator

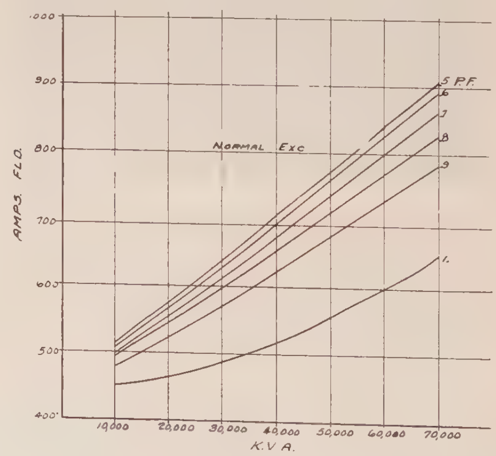

Fig. 9—Curves Showing Amperes, Excitation at 13,800 Volts for Various Loads and Power Factors of the 62,500-Kv-a. 1200-Rev. Generator

Fig. 8 shows efficiency curves as determined from the measured losses.

Fig. 9 shows excitation required for various power factors and loads at the normal volts—13,800.

Fig. 10 shows temperature rises attained under the different conditions of no excitation, normal excitation without load, and at partial loads and full load, with the voltage required by the system. It is to be noted that this generator has the remarkably low temperature of 50 deg. cent. rise under full load.

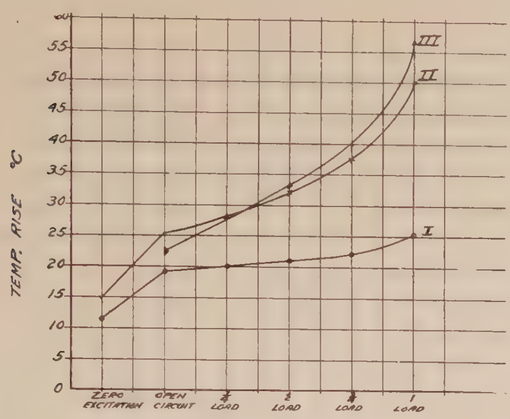

Fig. 10—Temperature Rises, 62,500-Kv-a. 1200-Rev. Generator

I. Temperature rise of air
II. Maximum temperature rise of armature winding by R. T. D.
III. Temperature rise of rotor winding by resistance

Ventilation

The ventilation of these large machines follows the well-known multi-path radial system used so successfully on generators of this type since 1913. Air is drawn in at each end of the machine through converging ducts formed by the end bells. Its pressure is elevated by multivane fans attached to each end of the rotor. These fans are so constructed that the air stream at each end of the machine is split into two parts, the inner section of fan feeding directly into the airgap and thence radially out through the ½-in. air ducts with which the core is supplied. The air from the outer section of the fan is carried through sheet iron ducts to a center compartment in the machine, whence it flows radially inward to the airgap, thence axially along the air-gap until it meets the first stream of air from the inner fan, whence it flows radially outward through the airducts. These two air streams are separated at the fan by a third, or inner shield, which also acts as a diffusing ring for the air which passes through the outer fan. See Fig. 11. This system of keeping the two air streams separate has shown better results than when the air is allowed to exhaust into a common chamber and seek its own distribution path through the generator. This is due in part to the diffusing effect of the inner ring and, second, to the characteristics of the fans themselves. On machines of this size it is sufficient to have only two multiple paths. In machines of greater length, or smaller diameter, it is necessary to resort to a larger number of multiple paths through the core. The decision as to the number of multiple paths that shall be used will depend on the velocities in the airgap and through the airducts. A large number of multiple paths will result in a high air duct velocity and low airgap velocity, with poor cooling for the rotor and maximum cooling for the stator. Few multiple paths result in low airduct velocity and maximum rotor cooling. The ideal distribution then would be one in which the airgap was kept running full of cool air and the air-duct velocity in the neighborhood of 4000 to 6000 feet per minute. Beyond this point the pressure drop to force the air through is greater than the gain in cooling and, therefore, undesirable. In very long machines, where the limit of mechanical possibilities has been strained, the ability to take all of the air into the ends of the machine becomes extremely difficult. When such conditions are met it seems desirable to do away with fans on the rotor and resort to external blowers. The adoption of external blowers has never been viewed with much favor by the operating engineers, due to the fact that it means another auxiliary added to the already overburdened list, and, second, due to a feeling on the part of most operators that the external blower as now built is not as reliable as fans attached to the rotor. These considerations have in the past more than outweighed the advantage of the higher efficiency which was to be

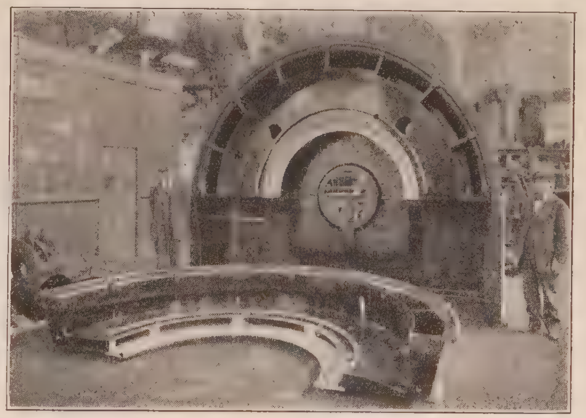

Fig. 11—One of the End Shields or Ventilation Housings for 62,500-Kv-a. 1200-Rev. per Min. Generator Showing in Foreground Upper Half Inner Shield Attached to Outer Shield, with Fire Protection Pipe at Inner Circumference

expected in the slow-speed blower. With the advent of the closed circuit system of ventilation in which the air is re-circulated, the losses being removed by surface coolers, new possibilities are introduced which make the consideration of external blowers at this time quite pertinent.

Owing to the limited space, the high peripheral speeds, and the difficulty of recovering the velocity head of air leaving the fan; the design of fans attached to the rotors of large turbine generators becomes difficult

and results in a fan of rather low efficiency. Since the air passes through these fans before entering the generator, the losses of fans are absorbed by the air, which results in the air entering the generator at some 5 deg. or 6 deg. higher temperature than would be the case if the fan losses were not absorbed. When it is considered that the total rise of air through the generator is only 20 deg. to 25 deg., the large sacrifice which must be made to supply sufficient air for ventilation and the handicap which is placed on the generator in the matter of temperatures are at once apparent. If, on the other hand, an external blower is used on a re-circulating system, and the blower is mounted ahead of the surface coolers, the temperature of the air entering the generator will be practically that of the air leaving the coolers, and the temperature of the generator, both stator and rotor, will be lower by the amount of heat which would have been absorbed in the air due to the fan losses. A second advantage of the external blower lies in the higher efficiency which it is possible to obtain. The question of reliability of these blowers is one which should not offer any serious obstacles when it is clearly known what the service requirements are.

General

The space for windings in the rotors of all steam turbine generators is limited by the high centrifugal forces. On the other hand, if the stator winding is correctly designed to be free from eddy currents, and slots of ample dimensions are provided, any desired low temperature of the windings may be secured when properly ventilated and insulated by materials of high thermal conductivity; hence, insofar as temperatures are concerned, the permissible electrical power output of a turbine generator need not be limited by the stator winding; provided the electrical stability is maintained, voltage regulation is commercially acceptable and the rating is maintained for which it is designed.

Although it may be said that no well-designed machine should be actually limited by any one element and in keeping with the principles of economy that the stator should be decreased until a balance is reached with the rotor, nevertheless, a certain freedom in design of the stator exists as to the control of losses and temperatures wherein no hard and fast boundary defines what is absolutely safe.

It will be impossible to include here any extended description of stator windings and the several methods which are now being used to partially or completely eliminate the circulating currents in the coils.

The stator conductors of either the bar or coil type consist of many thin rectangular strips of copper insulated by cotton or asbestos. Using a thin strand obtains small strand loss; the segregation of the strands permits the carrying out of the following methods of reducing the circulating current loss to a low value:

(a) Use of stranding continuously through two or more coils;

(b) Use of a total depth of copper in the slot, less than would be used if the d-c. resistance alone was considered;

(c) Use of a large number of circuits and turns per coil;

(d) Use of a two-turn coil turned over at one end only;

(e) Use of a twisted conductor;

(f) Use of coils having conductors segregated into groups and the groups carried separately through two or more coils by proper transpositions.

Losses

Fig. 8 shows the efficiencies of this generator at various power factors. Values upon which the efficiencies are based are made up of the well-known losses, such as friction and windage, core loss, $I^2 R$ of the armature and rotor, and also of certain losses which for a better term, and because they are usually associated with the loading of a machine, are called "load losses." It is not the purpose of this paper to go at any length into the source and magnitude of these last losses; the field is large enough to form the subject of a paper by itself. It is enough here to mention that losses do exist in all of what might be termed the inactive magnetic parts, as well as the active magnetic parts of the machine, and that these losses are of sufficient magnitude to have an effect on the efficiency of the machine. Under the heading of inactive magnetic parts might be classed the clamping flanges, the air shields, the dovetail ribs, frame, etc. Under the active magnetic parts might be classed the rotor core surface, retaining wedges, retaining rings, etc. The difficulties of actually determining magnitude and source of loss in these various parts, on, say, a 30,000-kw. machine, are as great, due to the difficulty in handling such enormous amounts of power, that the idea was conceived of building turbine-type generators in miniature and carrying out investigations on these little machines. Accordingly, two little machines were built which are in every essential detail an exact reproduction of the large machines, reduced in scale to one-third size, and, hence, in capacity to one-twenty-seventh. It is gratifying to record that the percentage losses shown by these little machines were in exact percentage agreement with the large machines. This does not include the $I^2 R$ of the copper, which is excessive. By substituting wood for the various inactive parts, such as shield, flanges, end fingers, etc., the magnitude of the losses in these various parts has been fairly accurately determined. The steel end rings, which retain the end windings of the rotor coils, have for sometime been under suspicion as being the source of considerable loss, although complete data are not available on these parts. Tests on the miniature generators revealed the fact that while there is magnetic field set up by the end turns of the armature winding, which rotates in synchronism with the end bells on the

rotor and, therefore, causes no loss, there is also a high-frequency harmonic flux which occasions a considerable loss in the end structure. These harmonic fluxes are probably associated with certain pitches of the armature winding and are worse with some pitches than with others. However, no exact data are available on this point. A very interesting feature in connection with these losses is that they bear a relation to the magnetic loading of the field. The armature end turns set up a magnetic circuit which interlinks the rotor end structure with the inactive magnetic, and a portion of the magnetic parts of the stator. Under conditions of sustained short-circuit, or of a leading power factor on the machine, under both of which conditions the magnetic loading of the rotor is small, the flux leakage paths are completely dominated by ampere turns of the armature and windings, and the losses are large. Under conditions where the machine is loaded, or where the power factor is lagging, the end turns of the rotor establish a counter m. m. f. which greatly changes both the direction and magnitude of the end flux leakage and this results in much lower losses and heating.

The data that have been and are being taken on this subject lead us to hope that at no distant time the uncertainty regarding the losses at heads of machines will be done away with and that machines of even higher efficiency than at present will be built.

As intimated above, it may be stated that the temperature rise of the rotor winding is greater than

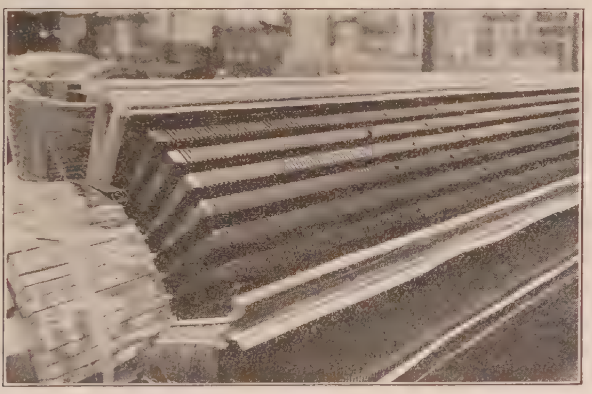

Fig. 12—Partially Wound Rotor of 31,250-Kv-a. Steam Turbine Generator Showing Circumferential Grooves in Solid Forged Rotor to Improve Ventilation and Reduce Pole Face Losses

it would be from the losses of the exciting current alone and the efficiency of the generator is reduced by the following additional losses of the rotor.

1. Friction of the rotor surface upon the cooling air.
2. Eddy currents at stator tooth frequency in the skin surface of the rotor steel. These are dependent upon the variable permeance of the slotted inner periphery of the stator core and the zigzag flux leakage to and from the rotor caused by the distribution of the m. m. f. in the stator slots.

It is now the general practise to groove the surface of the rotor body, see Fig. 12, and thereby secure lower temperature rises of the field winding and higher efficiency. Grooving of the surface with a coarse thread increases the cooling surface, reduces slightly the flow of air, and increases the turbulency of the cooling air in the air gap. It also increases the resistance to flow of high-frequency eddy currents, thus improving efficiency as well as reducing temperature. In all cases when tested it has been found that grooving has been beneficial.

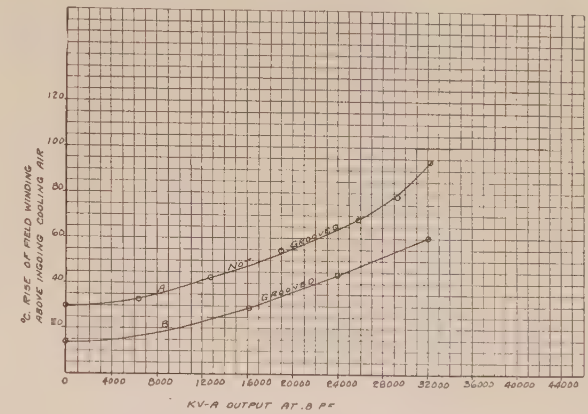

Fig. 13—Reduction in Temperature of Field Winding of 31,250-Kv-a. 13,200-Volt Generator Obtained by Grooving Rotor

An exceptional case of the improvement which has been registered by the grooving of the rotors is seen by observing in Fig. 13 the difference in temperature rises secured during tests upon two rotors identical in all respects except that one was grooved, the other not.

The tests determined the following:

1. The grooved rotor obtained a temperature rise of 58 deg. cent. at closely full-rated load as compared with a rise of 88 deg. cent. for the similar ungrooved rotor. A second grooved rotor tested in the same stator as the ungrooved rotor just mentioned obtained a temperature rise of 53 deg. cent. upon the field winding.
2. The core loss was reduced.
3. The rate of air flow before grooving was 69,200 cu. ft. per min. This was reduced to 54,000 cu. ft. per min. by grooving.
4. The stator was slightly reduced in temperature.
5. The efficiency was greatly improved.
6. The customer has had a third rotor grooved, tests upon which have not yet been made.

Fire Protection. It is particularly important, in connection with large totally enclosed generators, that they be equipped with protection against fire. Differential relay protection should be provided in order that excitation may be removed and the unit disconnected from the system in case of a break through the insulation. The differential relay protection is useful only in connection with dielectric failures. It sometimes happens that fire starts on the surface of the

insulation, without any electrical failure of the insulation. The exact causes of these fires are not always known but they are liable to occur under certain conditions, such as the accumulations of dirt, consisting of carbonized and other highly inflammable material. They are probably started by a spark resulting from some switching operation or sudden heavy short-circuit on the line. Such surface fires are hardly known, except in connection with large totally enclosed machines. It is possible in some cases to discover the presence of fire by means of smoke in the air discharge pipe, in which case it is usually best to immediately remove excitation, shut unit down and make examination. However, all large generators should be provided with equipment to put out fire, whether started by dielectric failure or on the surface of insulation by static spark or spark of any kind. It has become customary to equip these machines with pipes at both ends in proximity to the end windings, and with outlets so placed as to direct steam, water, or whatever agent is employed, in the most effective manner for putting out the fire. Steam and water are the agents that have been generally employed, although carbon dioxide gas has been installed in a few cases. The use of an inert gas, such as carbon dioxide, has a certain advantage over the use of steam or water, in that it causes no temporary or permanent injury to the insulation; furthermore, the operator who suspects a fire, will not wait so long to persuade himself that action must be taken if it is a matter of turning on the inert gas, as he would to turn on steam or water. Undoubtedly, the system of ventilation now coming rapidly into vogue, of re-circulating the same air and carrying off the heat by water-coolers, has a decided advantage in the matter of fighting fire, since the oxygen in the air becomes rapidly exhausted and the products of combustion serve as a fire extinguisher. Tests that have been made indicate that a 25 per cent saturation of carbon dioxide is ample to put out a fire. This system of ventilation prevents the accumulation of dirt, etc., and thus does away with surface fires.

Operating Conditions. The handling of the rotor by operators is of extreme importance. Probably everyone will concur in the statement that the ideal condition to maintain in large generator rotors is a constant temperature of such magnitude as 90 deg. or 100 deg. This is not possible, but efforts should be made to maintain temperatures that vary within as small a range as possible.

The distributed field winding assembled in numerous slots and secured against centrifugal force by metallic wedges in the slots, and by metallic binding bands at the heads, is peculiarly susceptible to deterioration if temperatures within the winding change frequently and through a wide range. To appreciate this, it is only necessary to consider the nature of the structure. There are three different materials, one of them a more or less intricate compound, that are subjected to the changing temperatures, and each of the materials has a temperature coefficient of its own quite different from that of the others. The temperature coefficient of the copper is the highest and about one and one-half times that of the steel in which it is embedded, and approximately two times that of the insulation that stands intermediate between copper and steel. To intensify these differences, the copper itself is always subjected to a much wider range in temperature than either the insulation or the rotor body proper, and to a quicker response to changing load. Common practise points to temperature rises in the copper of about 85 deg. cent. above the cooling medium, as the proper range to allow between the no-load starting and the full-load constant running conditions. By simple arithmetical applications of the formula for change of volume, due to temperature coefficient, we find the length of the field conductor in a 10-foot long slot for a quick 85 deg. change, to become ⅛ in. greater than the length of the envelope of insulation (except as the insulation stretches to accommodate itself to the pulling action of the coil) and 1/12 in. greater than the slot itself, in which the insulated coil is embedded. Undoubtedly, improved methods of forming up the insulation and of holding the winding against centrifugal force allow these movements to take place with very little deterioration, but it is greatly to be desired on the part of the operating people, that the variations in temperature be kept from exceeding 85 deg. cent.

A condition of operation to be avoided is that where the rotor is allowed, if the turbine is shut down, to reach a temperature approximating that of out-of-doors in our temperate climates during the cold season. Undoubtedly cases have existed in the near past, and probably at the present time, where the rotor temperature gets down to 0 deg. cent. after an overnight shut-down. If in such case the turbine is started up and loaded, and for reasons of personal comfort to operators the station air is used, the cooling air temperature will soon attain something like 25 deg. cent., and if for any reason an overload in kilowatts for short period is desired, or an unusual demand for power factor correction arises, requiring excitation amperes to be increased as much as 10 per cent over that stamped on the nameplate, the rotor temperatures may readily attain 135 deg. cent. In such case the unequal expansions of the various materials of the rotor that may occur within a few hours, undoubtedly exert mechanical strains that come with tremendous force on the insulation and must, when repeated often enough, result in disintegration. It is, therefore, strongly recommended to all operators of large steam turbine units, that they make a study of how to maintain the best conditions in the matter of temperature change in the rotor windings.

It is to be recommended:

1. that overloads in excitation be avoided;
2. that such arrangements of ventilation be adopted

as will permit as little cooling down of rotor when at rest as possible, and on no occasion permit the entrance direct of outdoor air;

3. that a practise be established of determining temperature of field winding at stated intervals by observing volts at collector rings and comparing it with that obtained at same load conditions when generator was first put into service;

4. that insulation resistance be measured at the same stated intervals;

5. if for any reason at any time rotor at rest has become very cold, run it at low speed with excitation sufficient to bring temperature up to about 75 deg. cent. in about one-half hour before raising speed to normal.

Possible Future Units. The possible size of a generator at any speed is limited if the designer produces a "stiff shaft" machine; by this we mean a generator whose rotor at normal speed operates below the critical speed. Assuming adherence to this practise, and to the same type of ventilation at the several speeds, *viz.*, whether by means of self-contained fans or external blowers, the possible size at the several speeds varies inversely as the square of the speed; thus, for 60-cycle generators, 8000-kw. (10,000 kv-a.) at 3600 rev. per min., corresponds to 32,000 kw. (40,000 kv-a.) at 1800 rev. per min. and to 72,000 kw. (90,000 kv-a.) at 1200 rev. per min. The largest sizes at all these speeds should be of high voltage, say 10,000 to 14,000, to permit of the use of a sufficient number of slots and have designs that will not result in too large amperage per slot.

In the matter of size as related to ventilation adopted, it can be greatly increased by the use of external blowers, since the number of multiple paths can be increased and valuable space saved between the rotor proper and the bearings at the two ends, space otherwise occupied by the fans and the chambers below and beyond them for the ingoing air. At the present moment 62,500-kv-a., 14,000-volt 60-cycle generators are being built at 1800 rev. per min. and 60,000-kw. 11,000-volt 25-cycle generators at 1500 rev. per min.

TRAINING COURSE IN LIGHTING

Today, the use of electrical energy for artificial illumination is so extensive that central stations can well afford to exert considerable effort in developing this phase of their business. It is only natural that the central station in any community should be looked upon by its customers as a source of information on proper electric lighting service and all that this implies. But, in spite of this fact, there are comparatively few central stations who can furnish what might be termed, illuminating engineering service.

The few central station companies who have organized illuminating engineering departments to fill the demand for this sort of service, testify to its value in promoting good will and building revenue. This service is of especial benefit to these companies because it leads toward better public relations. In view of these facts, other central station companies have sought competent, experienced illuminating engineers to undertake such work on their behalf. The present condition in this field, however, is such that men of sufficient competency and training are not to be had.

With this in mind the Lighting Bureau of the National Electric Light Association undertook to arrange for a course of training which would supply an essential ground work in lighting to men about to take up such work for central stations. Thus, with the cooperation of the Illuminating Engineering Society, a training course in lighting is now being presented to central station representatives. Throughout the months of July, August and September these men have been pursuing a home study course in illumination, which, like other courses of similar nature, requires written recitations at stated intervals of time. The examination on this portion of the course will be held on October 6th in Chicago, where the students will assemble previous to starting on a training tour. This tour starts in Chicago on October 6th; the itinerary will include such cities as Detroit, Cleveland, Washington, D. C., New York and Boston; in each of these cities examples of good and bad lighting will be visited and the various applications and manufacturing processes involved in the lighting industry will be studied and discussed. The training tour will terminate with the Convention of the Illuminating Engineering Society at Briar Cliff Lodge, New York, during the week of October 27th.

Due to the necessity of covering a great deal of ground in a short time and of providing the best possible groundwork to fit those taking the course to promote lighting improvements in their respective communities, it is proposed to make the training tour consist of solid work relieved only by a necessary minimum of sight seeing to break the routine of study and inspection.

The success of the course is assured since the very best men in the lighting field have been secured for giving these men all possible information which will further their advancement as illuminating engineers. They will attend the Convention of the Illuminating Engineering Society in order to make the acquaintance of the prominent engineers in the lighting industry, thus giving them a sort of prestige which it would otherwise be difficult to obtain.

The cost of the course will be borne by the central station companies and will amount to approximately $1,000 per man. This sum, however, is very small in comparison to that which would ordinarily be spent in the training of an illumination engineer by a central station; since much more time would ordinarily be required in the training of such a man through the medium of experience alone.

—July, *I. E. S. Transactions.*

Corona Losses Between Wires at Extra High Voltages—II

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Review of the Subject.—*Results of corona loss tests upon three sizes of cables at voltages varying from 100 to 620 kv. and spacings from 18 to 38 feet are reported from the Engineering Experiment Station of Purdue University. These tests results, reduced to the standard 1000 feet of transmission line, are compared with corresponding values calculated from Peek's formula for similar conditions of operation. A description of the tower line and method of measurement of the losses in the high-voltage circuit is included.*

An empirical equation has been developed which approximates quite closely the relation between corona loss and voltage for different spacings. The variations of the empirical coefficient of this equation are indicated for 2/0 and 4/0 cables.

Three methods of attacking the problem of modified transmission line design for the elimination of excessive corona losses between wires at extra high voltages have been outlined for further research and study.

I. Calculation of Capacity and Corresponding Radius of Equivalent Coronal Conductor and its Relation to Voltage between Wires.

II. Determination of Corona Losses between One Wire and Ground.

III. Photographic Reproduction of Equivalent Electrostatic Field Surrounding Model Conductors with Proportional Spacings between Wires and Ground.

The paper should be considered a progress report to be enlarged and analyzed further at a later time.

CORONA losses upon transmission lines may reach values worthy of the serious consideration of the designing and operating electrical engineer at or above potentials of 100 kilovolts between wires, depending upon the size and spacing of the wires, the weather conditions and the elevation of the line above sea level.

The critical voltage at which corona occurs upon a given transmission line and the magnitude of the power loss due to corona for definite line conditions may be calculated by means of the formulas developed by F. W. Peek, Jr., based upon certain empirical constants which were determined by him in early laboratory and experimental transmission line tests.[1] These tests included voltages up to a maximum of 250 kilovolts.

Tests carried on at Purdue University upon an experimental line 1380 feet in length were reported to the Institute in 1912.[2] These results were compared with those obtained upon other lines already in operation, as well as those calculated from Peek's formula. These tests were made with instruments connected in the high-voltage circuit and therefore were subject to no error depending upon the efficiency or power factor at which the stepup transformers were operating. The following significant conclusions may be quoted from the latter paper:

"Corona loss may be readily and accurately determined with instruments connected directly into the high-tension circuit.

"Corona loss curves are parabolas, the constants of the equations being different above and below the visual critical voltage.

"Test values checked results calculated from Peek's formula for points above the visual critical voltage with a fair degree of accuracy, especially at the wider spacings between wires.

"Variations from Peek's formula were in the direction of greater losses for a given voltage than those given by the formula. This was also found to be true of the tests which have been made upon operating lines, when the latter were reduced to a common standard for comparison."

This paper sets forth the results of tests carried on at Purdue University during the past two years with a single-phase line designed for 600 kilovolts. The corona losses were measured upon three standard sizes of cables at various spacings by means of a wattmeter in the high-voltage circuit operating at voltages as high as 620 kilovolts. These losses have been compared with values calculated by means of Peek's formula for similar cable size, spacing and operating conditions and representative curves have been plotted for both test and calculated values. The applicability of this formula and the possible error to be expected in its use therefore became apparent for calculations of corona losses at voltages in excess of those within which the original empirical constants were determined. In all cases, the test and calculated results have been reduced to the standard length of line of 1000 feet. Since there is now a practical demand for transmission lines to be operated at voltages in excess of those considered a maximum at the time the former tests were completed, it becomes a matter of particular concern to determine and record these corona loss measurements and their relation to calculated values.

The line upon which these tests were made was 1710 feet in length. It consisted of three equal spans of cables supported upon semi-flexible steel towers 65 feet in height. The towers at either end of the line were of similar design longitudinally guyed to withstand the

1. See Paper by F. W. Peek, Jr., on "Law of Corona" TRANSACTIONS A. I. E. E., Vol. XXX, Part III, p. 1889.

2. "Corona Losses between Wires at High Voltages I" by C. Francis Harding, TRANSACTIONS A. I. E. E., Vol. XXXI, Part 1, p. 1035.

Abridgment of paper to be presented at the Pacific Coast Convention of the A. I. E. E., Pasadena Cal., October 13-17, 1924.

dead-end stresses. The cables were supported by means of standard suspension insulators of fifteen units each, hung from movable carriages which were designed with rollers to operate transversely upon a steel cross arm 40 feet in length supported upon each tower. The spacing between the two cables in the same horizontal plane could thus be readily changed by increments of from two to four feet between the limits of 18 feet and

FIG. 1—CORONA AT NIGHT 600 KV.

38 feet. Three sizes of stranded aluminum cables with steel cores rated as 2/0, 4/0 B & S and 500,000 cm., have been tested to date.

The feeders connecting the test line with the transformers of the high-voltage laboratory were of particularly large cross-section and were spaced relatively far apart in order to reduce the tare losses which were subtracted from the gross power measurement to determine the net corona losses upon the test line.

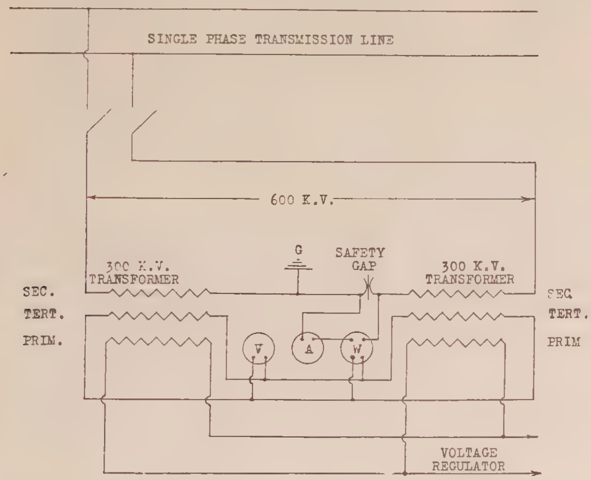

FIG. 2—DIAGRAM OF TRANSFORMER CONNECTIONS

Two identical transformers, purchased from the Westinghouse Electric and Mfg. Co., rated as 135 kv-a., 300 kv., 60-cycle oil-insulated units with 1900-volt double-coil primaries were used for the power supply. One secondary terminal of each transformer was connected to one side of the single-phase circuit through a condenser bushing, while the other end of each secondary winding was connected to ground through the indicating instruments. Safety spark-gaps were shunted around the instruments for protection in case of an open circuit. The secondaries of the two transformers were connected in series for line voltages in excess of 300 kv., while the two coils of each primary winding might be connected either in series or in parallel for the varying ratios of transformation desired.

The variation of voltage was accomplished very satisfactorily without wave-form distortion, by means of an auxiliary regulating transformer with tapped primary, whose connections were varied by means of a motor-driven drum controller. The entire ranges of voltage, up to maximum values of 150, 300, or 600 kv., could be readily traversed throughout 480 equal increments at a definite predetermined rate, or any desired voltage could be held constant, or varied slightly at will, by means of the auxiliary hand control.

The gross power output of the two 300-kv. transformers with their secondary windings connected in series (Fig. 2) was measured very accurately by means

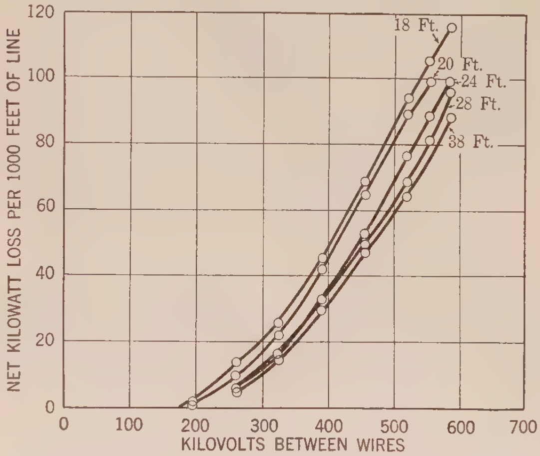

FIG. 3—NET CORONA LOSS PER 1000 FT. OF LINE 2/0 CABLE

of a specially calibrated indicating wattmeter whose current coil was connected in series with the high-voltage transformer winding. The voltmeter and the potential coil of the wattmeter were supplied with a voltage proportional to the line voltage through the agency of a tertiary coil in each transformer. These tertiary coil voltages were very carefully calibrated by means of the A. I. E. E. standard 50-cm. sphere-gap measurements under the two different conditions of the line being connected and disconnected from the step-up transformers.

An additional check was made to insure the accuracy of ratio of line to tertiary coil voltage applied to voltmeter and wattmeter measurements under test conditions with large corona loads upon the line. A standard A. I. E. E., 50-cm. sphere-gap with neither sphere grounded was connected across the line, and readings taken of tertiary coil voltmeter at the moment of spark-over of the sphere-gap at various standard settings. These calibrations were made over the entire

range of voltage involved in the tests. As the experimental line, although open-circuited at the further end, is not long enough to cause abnormal voltages to be induced therein, it is believed that the losses due to corona, at the voltages herein specified, have, therefore, been accurately determined. Furthermore, it is probable that the leakage losses over insulators which necessarily form a part of the net losses on the line proper after the feeder corona and insulator tare have been subtracted, are entirely negligible. This may be assumed to be true because only four suspension insulators per cable were involved and for the further reason that great care was exercised to make sure that all units were in good condition throughout the series of tests. In previous tests reported to the Institute[3] in which precautions were taken to subtract the line insulator leakage losses, it was found that such were negligible with the insulators in first-class condition.

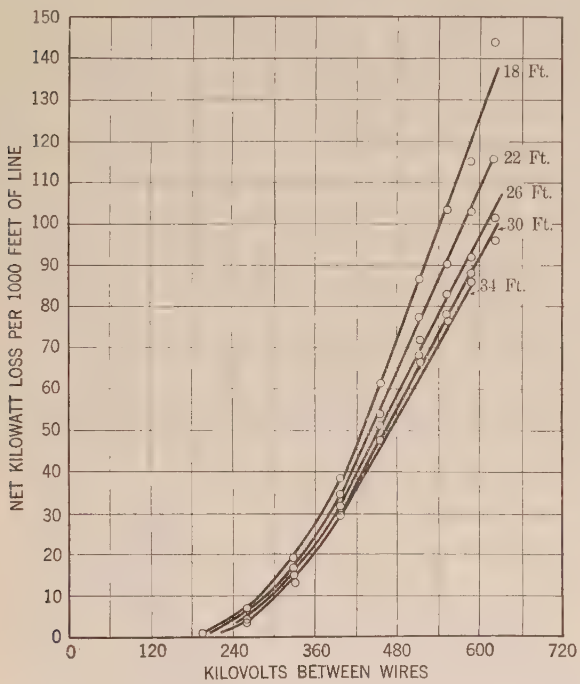

Fig. 4—Net Corona Loss per 1000 Ft. of Line 4/0 Cable

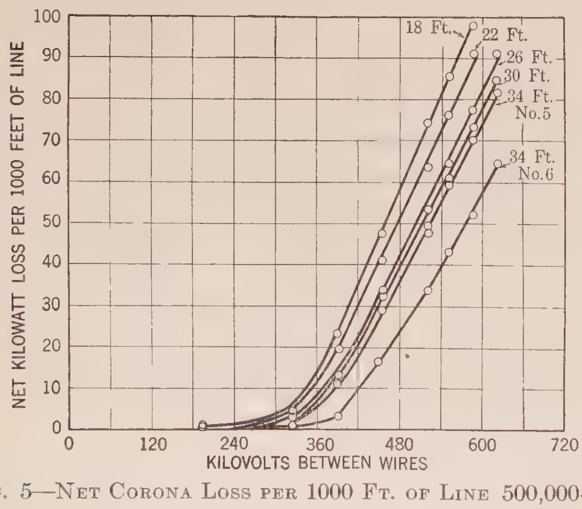

Fig. 5—Net Corona Loss per 1000 Ft. of Line 500,000-Cm. Cable

Results of Tests

In the Appendix, Tables I to XIX inclusive, will be found the results of the tests upon the three sizes of wires under consideration for five or more spacings. The weather conditions, including temperature and barometric pressure at the time of the test, are also recorded. The latter data provide means for calculating the values given in the last column of the tables from Peek's formula, for which a typical solution will be found for one test condition in the Appendix as an illustration of the method followed.

The curves of Figs. 3, 4 and 5 also represent the net corona losses, reduced to a standard length of 1000 feet of line for the three sizes of cables tested at spacings from 18 to 38 feet apart. It will be noted that in spite of the fact that these tests were made during a considerable range of temperature and barometric pressure, due to natural weather conditions, the wider spacings and the larger cables at the same spacings show consistently lower corona losses at any common voltage. This confirms the results to be expected from the theory of corona.

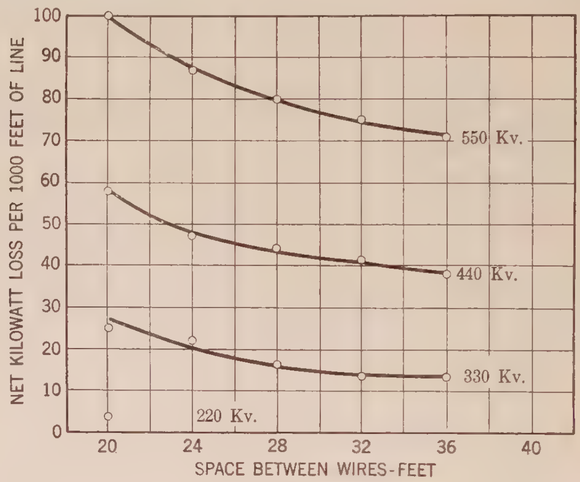

Fig. 6—Net Corona Loss per 1000 Ft. of Line Constant Voltage, Variable Spacing 2/0 Cable

The relation between corona losses and cable spacing are shown in Figs. 6, 7 and 8 at three definite voltages, determined graphically, from curves of Figs. 3, 4 and 5. These points, with two minor exceptions, fall upon smooth curves, apparently following a definite law which indicates, as would be expected, a marked and regular decrease in loss with increased spacing between cables.

3. "Corona Losses between Wires at High Voltages I" by C. Francis Harding, Transactions A. I. E. E., Vol. XXXI, Part 1, p. 1036.

These curves further indicate the zones of voltage and spacing for the three sizes of cables within which the losses are not excessive from the practical standpoint. For example, if it soon becomes desirable to operate a line at 330 kilovolts, the losses are found from Fig. 8 to be moderate for the 500,000 cm. aluminum stranded cable. However, with 2/0 and 4/0 cables these losses

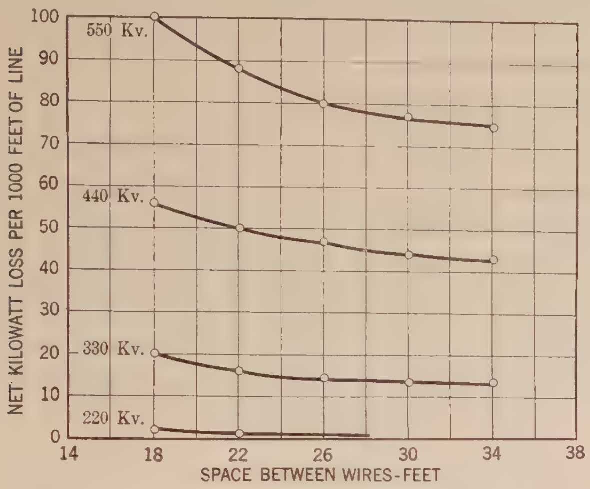

FIG. 7—NET CORONA LOSS PER 1000 FT. OF LINE CONSTANT VOLTAGE, VARIABLE SPACING 4/0 CABLE

are objectionably large, particularly at the narrow spacings. At 220 kilovolts between cables, a potential at which some lines are already operating, the corona losses are negligible, especially for the largest size of cable.

It should be noted that all results in this paper are plotted for single-phase circuits. The corresponding

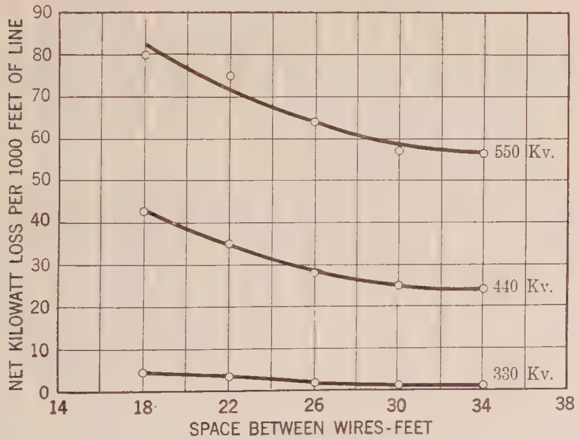

FIG. 8—NET CORONA LOSS PER 1000 FT. OF LINE CONSTANT VOLTAGE, VARIABLE SPACING 500,000-CM. CABLE

losses per 1000 feet of the normal three-phase line can be obtained from these curves by referring to a value of kilovolts between wires $\frac{2}{\sqrt{3}}$ times as great as the single-phase line voltage and by multiplying the resultant net loss in kilowatts taken from the curves by $\frac{3}{2}$ to include the loss upon all three wires.

For example, to determine the net three-phase corona loss per 1000 feet of line consisting of three 500,000-cm. cables spaced 26 feet apart at a voltage of 220 kv. between cables, the corresponding single-phase curve of Fig. 5 should be consulted for a voltage between wires of $\frac{220 \times 2}{\sqrt{3}} = 254$ kv. The corresponding power loss is found to be 0.33 kw. This is the loss per 1000 feet of two-wire line having the same voltage to neutral as a 220-kv. three-phase line. The three-wire, three-phase line will, therefore, have a loss of $\frac{3}{2} \times 0.33 = 0.495$ kw. per 1000 feet, or 2.62 kw. per mile. A similar

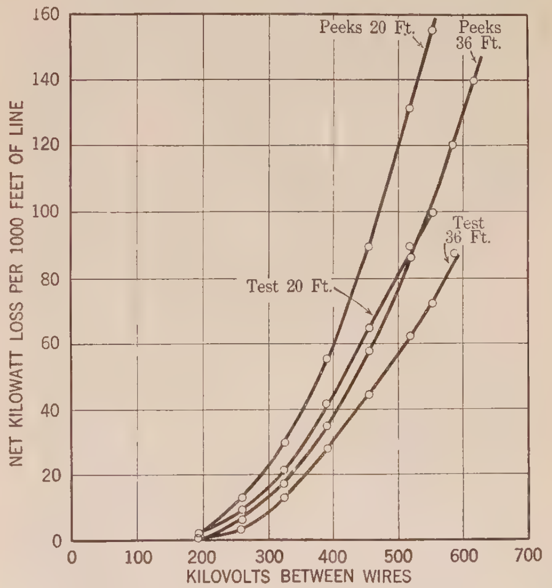

FIG. 9—NET CORONA LOSS PER 1000 FT. OF LINE COMPARISON WITH PEEK'S FORMULA 2/0 CABLE

calculation for a possible 330 kv. three-phase line having the same size of cable and the same spacing, indicates a probable loss of $\frac{13.5 \times 3}{2} = 20.25$ kw. per 1000 feet, or 107.0 kw. per mile. This would obviously be excessive and would, therefore, involve a change of design for a line to operate efficiently at such a voltage.

Comparison with Calculated Values. A complete analysis of the comparative results of tests and corresponding losses calculated for the same weather conditions, based upon Peek's formula, was not possible in the time available since the completion of the tests.

It is evident, however, from values in the tables and Figs. 9, 10 and 11, in which such comparable results are plotted, that the calculated values are consistently higher than test values *throughout the higher ranges of*

voltage. This departure of actual losses determined by the tests from the calculated losses seems to be particularly noticeable at the narrow spacings and with the smaller sizes of cable. For example, it is apparent from

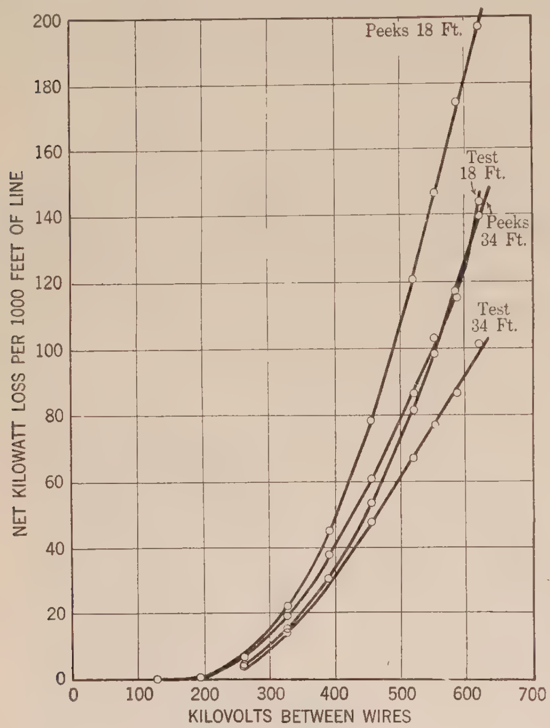

FIG. 10—NET CORONA LOSS PER 1000 FT. OF LINE COMPARISON WITH PEEK'S FORMULA 4/0 CABLE

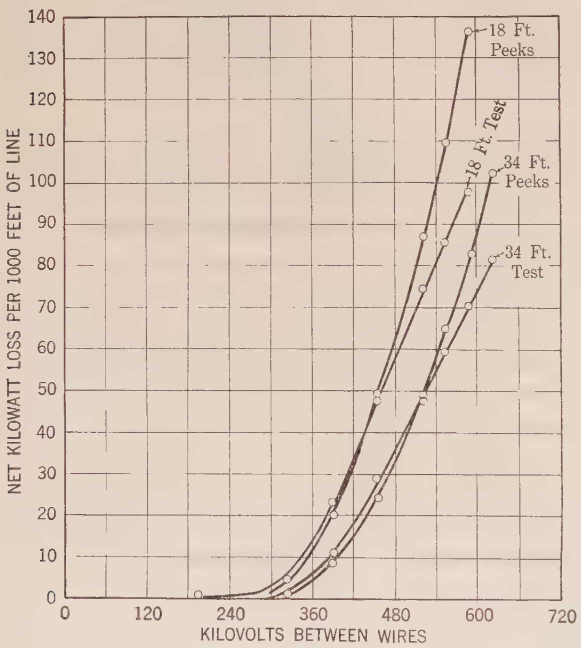

FIG. 11—NET CORONA LOSS PER 1000 FT. OF LINE COMPARISON WITH PEEK'S FORMULA 500,000-CM. CABLE

Fig. 10 that for 4/0 cable the calculated and test values are practically coincident for 18-foot spacing up to voltages not exceeding 300 kv., while the 34-foot spacing for the same cable indicated a coincidence up to 400 kv. For the 500,000-cm. cable, whose net test losses due to corona are superimposed upon the theoretical curves in Fig. 11, the calculated and test results are practically coincident up to 450 kv. for the 18-foot spacing and 520 kv. for the 34-foot spacing, the formula giving higher values of losses above and lower values below these voltages. Fig. 9 indicates a marked departure at the higher voltages of test from predicted values in the case of 2/0 cable for both narrow and wide spacings.

Test results are consistent with those reported at lower voltages in the first paper, since the theoretical calculation indicates losses less than the test values throughout the lower range of line voltages, while the former calculated values have a steeper slope upward with increased voltages than those found in the tests. In fact, the net losses throughout the higher range of line voltages, during the latter tests, seemed to follow a straight line or a modified quadratic law, rather than the parabola of the formula, thereby showing lower values of loss than those calculated.

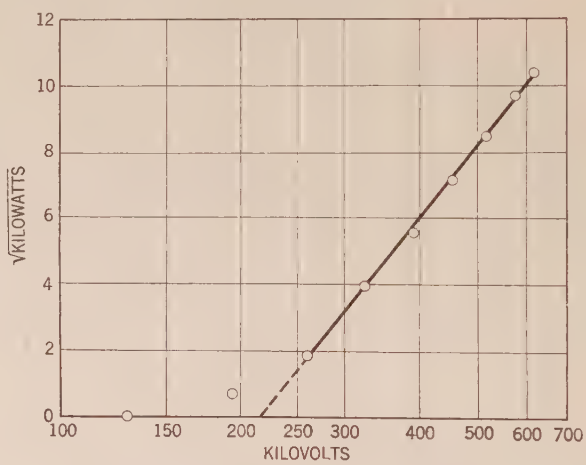

FIG. 12—TYPICAL LINEAR RELATION BETWEEN KW. AND LOG KV. FOR 2/0 CABLE, 26-FT. SPACING

The tests upon 4/0 cable were further studied to determine, if possible, an empirical equation for the curves representing net corona losses. The values representing the square-root of the losses expressed in kilowatts, plotted against kilovolts, do not develop the linear relation. If, however, they be plotted to a logarithmic scale of kilovolts (as illustrated in Fig. 12 for the spacing of 26 feet between cables), the straight line results. This indicates an equation of the form:

P (Corona loss in kw.) $= C \log_{10}{}^2$ kv./kv.$_1$ where C is a function of the spacing (s), as indicated for both 2/0 and 4/0 cable in Fig. 13.

The voltage kv.$_1$ determined by the intercept for zero corona loss, as indicated in Fig. 12, is found to be 215 kv. for 4/0 cable or $P = C \log_{10}{}^2 \dfrac{\text{kv.}}{215}$.

It is rather significant that the values of C, which are

obviously proportional to the corona loss, approach a minimum value as the spacing between cables is increased. An apparent critical or unstable condition seems to exist for these two cable sizes, for spacings between 30 and 38 feet under these test conditions. It will be of interest to determine by subsequent tests whether this is due to the distortional effect upon the electrostatic field of the conductors at wide spacings

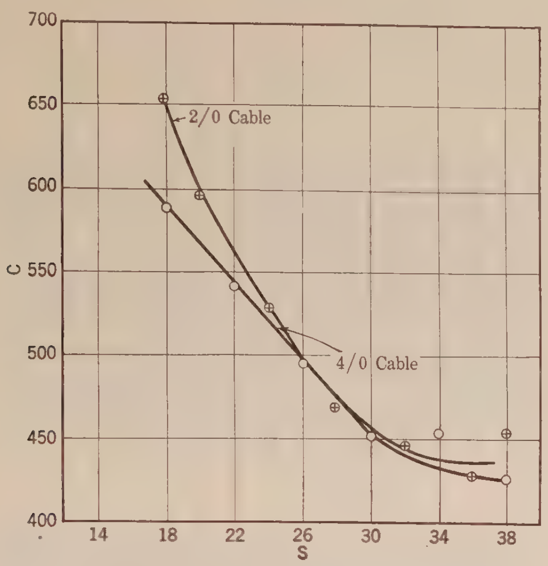

Fig. 13—Relation between Empirical Coefficient (C) and Spacing for 2/0 and 4/0 Cable

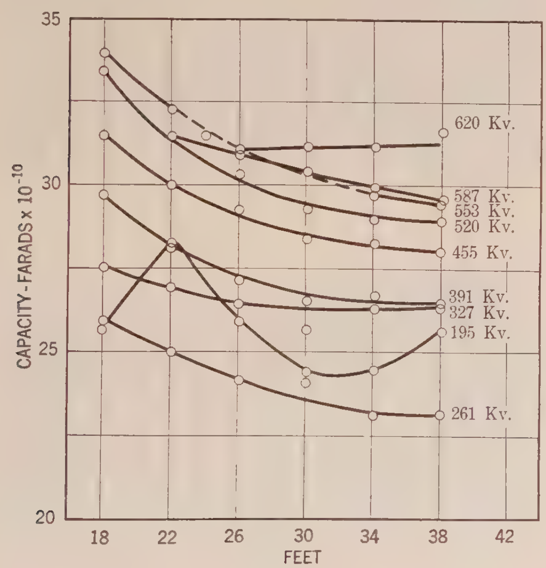

Fig. 14—Relation of Equivalent Capacity of Coronal Conductor and Spacing at Various Constant Potentials for 4/0 Cable

resulting from the proximity to the ground, or whether the "equivalent coronal conductor," if it may be called such, created by the ionization of the air surrounding the line wire, under excessive corona, becomes of such diameter or form as to produce a distinct localized minimum, or possibly a constant minimum loss independent of further increase of spacing.

Such possibilities immediately suggested three further studies, which have been undertaken in part as follows:

I. Calculation of Capacity and Corresponding Radius of Equivalent Coronal Conductor and its Relation to Voltage between Wires.

II. Determination of Corona Losses between One Wire and Ground.

III. Photographic Reproduction of Equivalent Electrostatic Field Surrounding Model Conductors with Proportional Spacings between Wires and Ground.

The tentative results of these three investigations are briefly summarized as follows:

I. Capacity and Corresponding Radius of Equivalent Coronal Conductor.

The capacity of an equivalent conducting body of

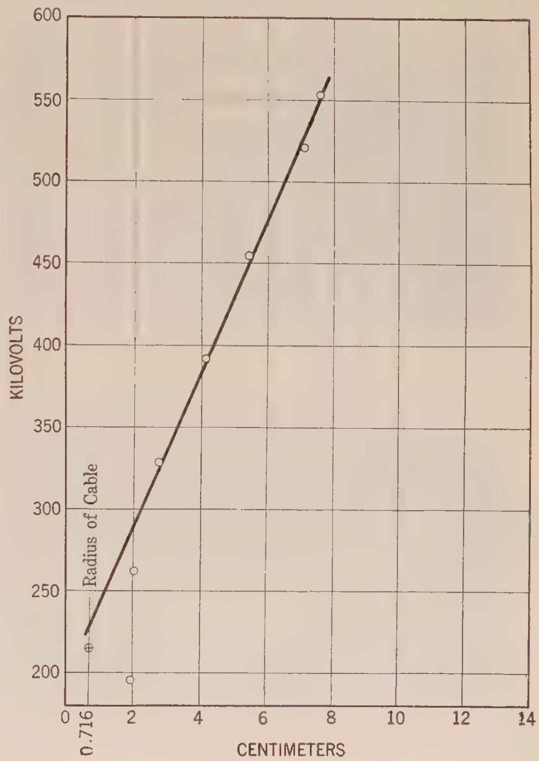

Fig. 15—Relation of Radius of Equivalent Coronal Conductor to Voltage between Wires at 18-Ft. Spacing

corona or apparent corona, which has been assumed to be a cylinder, concentrically located with respect to the line wire, may be readily calculated from the test data available in the tables of the Appendix. The net corona power loss for each voltage and the corresponding current and frequency being known, the power factor was determined and recorded in column 6 of each table. The reactive or capacity component of the total current becomes known, therefore, and the equivalent capacity and radius of the enlarged hypothetical conducting coronal cylinder may be determined for any test frequency. A sample calculation of such capacity and radius is included in the Appendix as an illustration.

The relation between such calculated capacities and the spacing between two 4/0 line wires for certain

indicated constant voltages ranging from 195 kv. to 620 kv. is plotted in Fig. 14. It is particularly interesting to observe that for such wires at 620 kv., the capacity is practically constant for spacings extending

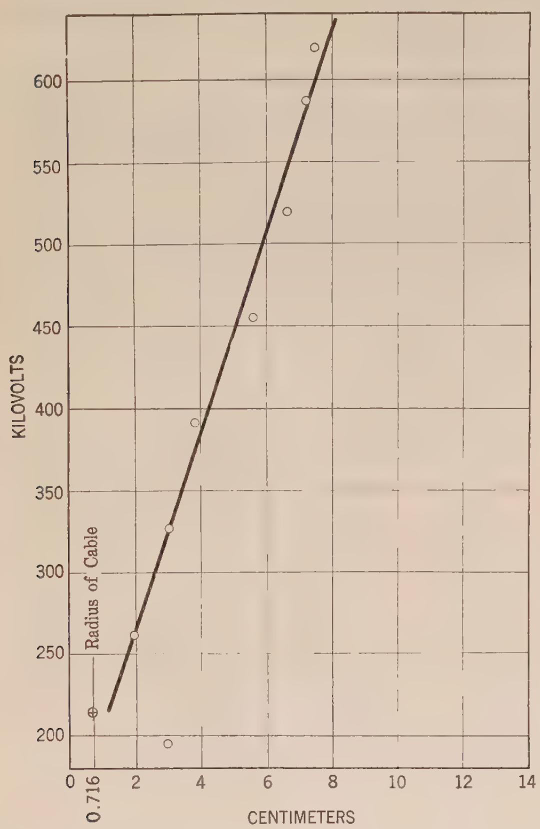

Fig. 16—Relation of Radius of Equivalent Coronal Conductor to Voltage between Wires at 26-Ft. Spacing

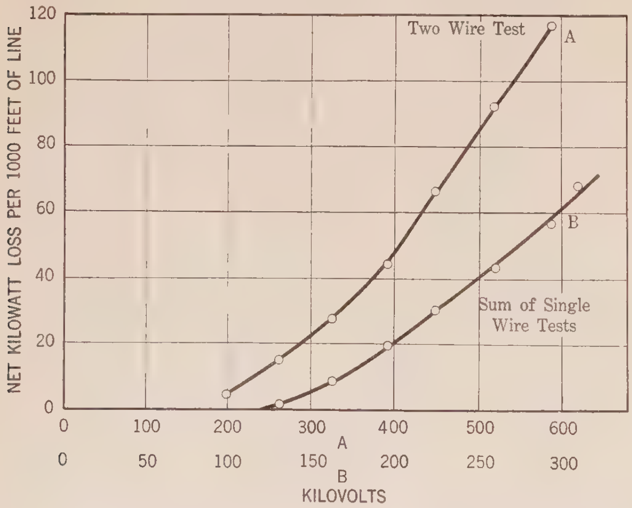

Fig. 17—Comparison of Corona Losses of One 4/0 Wire to Ground with Losses between Two 4/0 Wires, 18-Ft. Spacing

from 26 to 38 feet and probably beyond if the tests be extended, while at lower voltages the trend is toward smaller capacities as the spacings are increased and as the voltages for a given spacing are decreased. This condition is such as would be expected from the theory of the electrostatic circuit involved. The erratic variation of the equivalent capacity indicated by the curve for 195 kv. is also of interest, since this voltage is below the critical corona-forming voltage for such a cable. The irregularity of the curve is probably another confirmation of the well-known unstable condition surrounding such a wire when operating at a voltage approximating the critical corona potential.

If this investigation be extended to the determination of the radius of the equivalent coronal conductor, as previously indicated, the relations between such radii, expressed in centimeters, and the potentials impressed between two 4/0 wires of such a transmission line, spaced 18 and 26 feet apart, are available for further study in Figs. 15 and 16 respectively. As a basis of reference, the actual radius of the cable, which is 0.716 cm. in this case, has been plotted at a point corre-

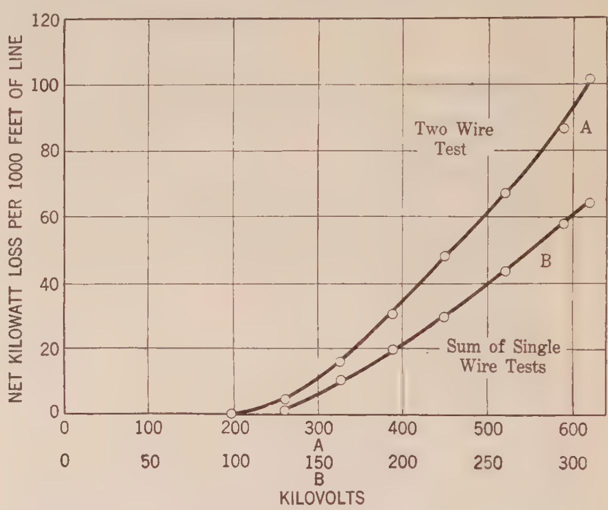

Fig. 18—Comparison of Corona Losses of One 4/0 Wire to Ground with Losses between Two 4/0 Wires, 34-Ft. Spacing

sponding approximately to the critical voltage of such a cable under the conditions of operation.

It will be noted that the trend of the variation of such radii with voltage is, in general, a linear one with a greater trend toward the larger radii for the smaller spacings. The points resulting from test values at or below the critical voltage again show an erratic behaviour, departing radically from the linear relation. In some of the other charts analyzed, but not reproduced in this paper, a very marked but probably purely incidental symmetry of fluctuation of such alternate points upon either side of the linear trend graph was particularly noted.

Although the practical bearing of this latter investigation may be far from obvious, it is probable that it may have a part to play in the determination of conductor diameters and spacings to be used for the higher voltages for power transmission in the future.

Corona Losses between Wires and Ground

Tests were conducted with the various sizes and spacings of wires upon the experimental transmission line with voltages increasing to a maximum of 300 kv. between one wire and ground. The other wire remained in place, at a definite spacing, but was disconnected from the high-voltage source and ungrounded.

An indication of the trend of such test data is evidenced by Tables XX and XXI in the Appendix and the composite curves of Figs. 17 and 18. As the spacing between wires is increased, especially if they are supported from relatively low towers, the effect of the neutral plane of the ground itself evidently becomes of importance, especially in determining proper corona eliminating designs for multi-circuit, super-voltage lines. It is to be expected for such spacings, as confirmed by these tests, that the arithmetical sum of the power losses due to corona between each wire individually and ground is very much less than the loss between wires at the same spacing. As the spacing is increased, however, this difference becomes less marked. The limiting factors in this relation at the higher voltages are yet to be determined, as they involve the relative costs of extra high towers as compared with wide rights of way for such long distance lines to be constructed in the future.

Studies of Electrostatic Fields Looking at Ends of Parallel Wires at Various Spacings. All 65 Mm. Above Ground (Fig. 19-26)

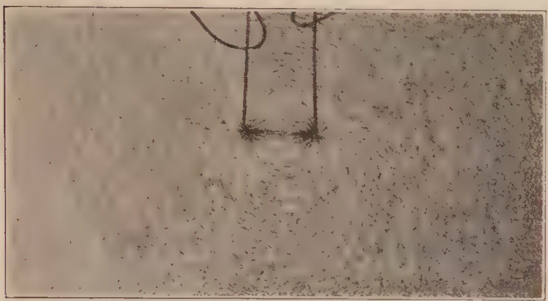

Fig. 19—Spacing, 18 Mm.

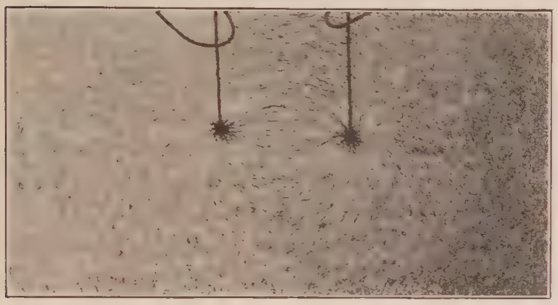

Fig. 20—Spacing, 38 Mm.

Fig. 21—One Wire and Ground

Reproduction of Electrostatic Field between Wires and Ground

The attempt which was made to apply the method of equivalent córonal conductor capacities and their radii, previously described herein, to the effect of the ground in cases involving wide spacings of wires, resulted in erratic values, probably due to necessarily badly distorted resultant electrostatic fields.

Fig. 22—Spacing, 32 Mm., Right Wire Disconnected

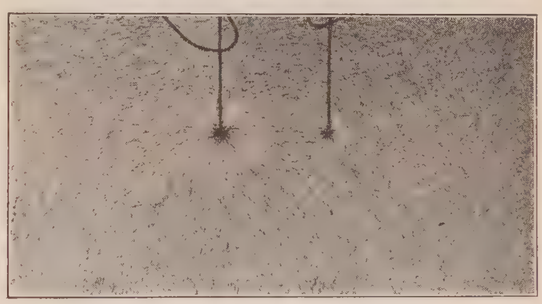

Fig. 23—Spacing, 32 Mm., Right Wire Grounded

The physical conception of this condition will, no doubt, be made clearer by the use of a method of photographing an equivalent model electrostatic field which has been recently originated by R. H. George, Research Assistant of the Engineering Experiment Station of Purdue University. Although this method was developed for another purpose, which will be published at an early date[4], its adaptation to this problem will be evident from inspection of Figs. 19 to 26 inclusive.

The scale of spacing in the model is proportional to the transmission line under consideration, one milli-

4. Forthcoming Bulletin, Engineering Experiment Station, Purdue University, Lafayette, Ind. "Improved Method of Visualizing and Studying The Electrostatic Field" by R. H. George, Research Assistant.

meter of the model corresponding to one foot on the actual line. In order that the effects of the same relative changes in spacing of conductors and the application of corresponding potentials between one and two wires and ground might be duplicated as closely as possible, the voltage for Figs. 19 to 26 was held constant. The captions of the illustrations will, no doubt, adequately explain the effects of ground potentials upon field distortion for wide conductor spacing.

Tests Under Abnormal Conditions. Two tests which were made under rather unusual weather conditions, seem to merit especial comment. Reference to Fig. 5 will reveal two tests upon 500,000-cm. cable at 34-foot spacing. Curve 5 in this graph represents a test during a rain storm with a temperature of + 3 deg. cent. and a barometer reading of 73.4 cm. The losses were relatively high in spite of the low temperature which would tend to produce lower losses than those of the average temperature of the other tests. Curve 6 was run upon a clear cold winter day with sleet upon the cables. The temperature was − 7.5 deg. cent. and the barometer 75.2 cm., as a result of which with the possible added effect of the enlarged conductor due to sleet formation, the loss was exceptionally low.

Fig. 24—Spacing 32 Mm., Potential between Wires

Fig. 25—Spacing, 65 Mm., Potential between Wires

Fig. 26—Spacing, 65 Mm., Right Wire Grounded

The tests are being continued upon other sizes of cables with varying conditions of operation, in order that a more detailed analysis may be made in a subsequent paper of actual results throughout this range of voltage.

Acknowledgment

The author desires to express his appreciation of the cooperation extended to the Engineering Experiment Station and School of Electrical Engineering of Purdue University by the following manufacturing companies, staff members and students, who provided materials and time for the design and construction of the line and for the tests reported in this paper:

The towers were furnished by the Bates Expanded Steel Truss Co., and the cables by the Aluminum Company of America. Insulators were used upon the line from the General Electric, Locke, Lapp, Westinghouse, Thomas, Ohio Brass and Jeffry Dewitt Companies.

Dr. W. E. Edington, Assistant Professor of Mathematics, Purdue University, who has devoted a portion of his time to the work of the Engineering Experiment Station, has assisted materially in the preparation of this paper. R. H. George and K. A. Oplinger, Research Assistants in the Engineering Experiment Station, operated the transformers, supervised the tests and checked all calculations. The following students of electrical engineering carried out much of the detailed construction upon the transmission line, took the readings under immediate supervision, and made calculations of the tests under the direction of the author:—

Design and Construction of Line: R. J. Rhinehart, A. Lorber, J. H. Brecheisen and H. O. Mathews.

Tests on 4/0 Cable: F. M. Holaday, P. W. Harrison, J. R. Parnin, W. F. Spaulding and W. J. Guenther.

Tests on 500,000 cm. Cable: F. C. Jones, M. S. Watson, K. O. Thorp, E. J. Archbold, R. C. Goodwin, K. T. Kwo and W. A. Sevedge.

Tests on 2/0 Cable: B. D. Holley, I. H. Hollis, W. J. Rannells, R. S. Merchant, D. Rasmussen and R. J. Morrison.

ELECTRIC STRAIN GAGE

In cooperation with Engineering Foundation, the design of a carbon resistor cartridge for measuring deformation in mass concrete has been undertaken with particular reference to the study of arch dams. A design has been completed and an experimental cartridge made up which is now being given a series of laboratory trials to determine temperature and other effects. It is planned to make up a number of these cartridges and embed them in concrete with a view of determining the effects of shrinkage and other factors as an aid to interpreting results obtained in field work.

Power Measurements at High Voltages and Low Power Factors

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Non-Member

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GEORGE R. STRAY
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Review of the Subject.—*A description is given of the apparatus for the measurement of power as low as a fraction of a watt at power factors approaching zero and voltages as high as 175 kv. to neutral. A standard make of portable wattmeter was used having maximum ranges of 1.5 watts, 37.5, 75 and 150 volts and 20 per cent power factor. To this wattmeter was adapted a three-megohm water column resistance multiplier.*

In the original form of the wattmeter the origins of certain errors, due to capacitances chiefly, were studied and methods for their elimination were subsequently determined. Integrity tests were developed by which the values of error powers were obtained and used as guides in making subsequent adjustments for the reduction of such errors to zero. These integrity tests were checked by using the wattmeter for the measurement of known amounts of power.

Reconnaissance studies were made of the voltage-corona power loss relations for rope laid copper, 0.91-in., lock wire smooth copper, 0.91-in. and concentric strand aluminum, 1.006-in. diameter transmission line conductors in rain and fair weather at differing degrees of humidity, temperatures, and barometric pressures, from "initial" to "full" corona formation. This class of studies was extended to corona loss values as offered by a wide variation of the "surface roughness" of conductors subjected to high voltages. The losses for a single brush were measured and the shielding effect of groups of brushes was studied. Losses to single strings of insulators under different conditions were determined.

THE sensitive, low-power factor, high-voltage wattmeter has been awaiting solution through twenty years or more. In the meantime, because of the lack of this wattmeter, satisfactory dimensional data over a wide range of important high-voltage actions have been difficult if not impossible to obtain. The promise for success of the high-voltage wattmeter using a water column resistance multiplier, leads to the conviction that it could be improved considerably, and that a series of high-voltage reconnaissance tests could be undertaken that would define lines along which further helpful studies could be made of the losses produced in brush discharges, local corona and insulators on high-voltage power transmission lines under conditions varying as to equipment forms, climate and altitude. The primary purpose of the present undertaking was, therefore, to make a series of reconnaissance tests of the above sort after improving the accuracy of the high-voltage wattmeter to the requisite degree.

The following study was made of the origin, nature and elimination of the errors occurring in the high-voltage wattmeter reported upon concurrently by Clark and Miller,[1] which will be referred to hereafter as the 1923 wattmeter.

At the outset of the work, when engaged upon laboratory transmission line corona loss measurements, certain peculiarities were observed in the indications of the wattmeter when the coil connections were changed. There were many possibilities as to the cause of the trouble. A systematic study of them was, therefore, made.

The usual low-voltage wattmeter errors such as self- and mutual-inductance of coils, electrostatic attraction, wave form, frequency, etc., were soon found to be negligible in the present case. The most serious of these, self-induction of the potential coil, produced, at the most, only 1 per cent error. The important source of error was found to be the capacitance in multiple with instrument coils. The schematic diagram of connections, Fig. 1, shows that the leads and their shields in the water column and line constitute condensers which shunt the wattmeter coils. These act to produce error by causing currents in the coils to differ from those in the water column and line, both in magnitude and

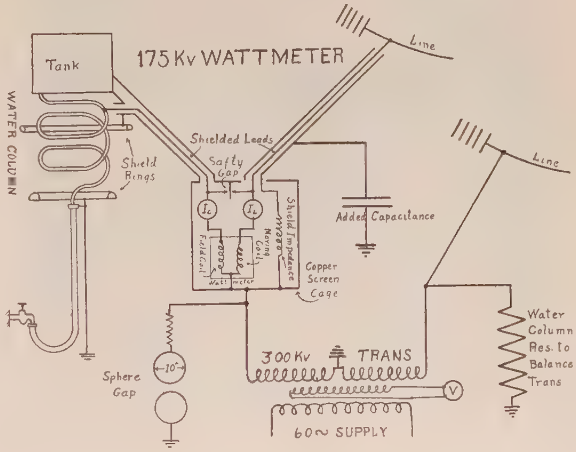


FIG. 1

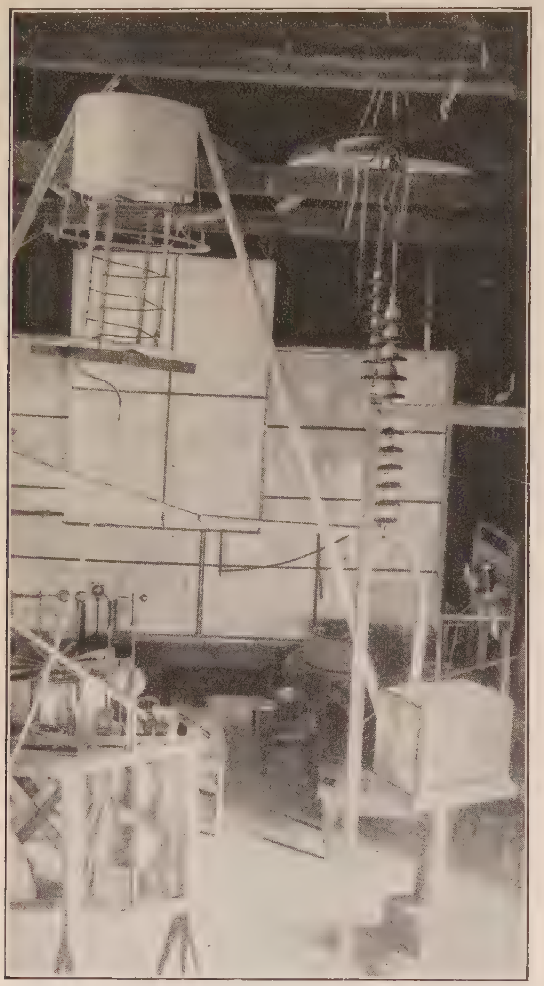
phase position. Of these, the shift in phase is the only one of importance and is constant for fixed connections. The error reading, due to capacitance across the coil in series with the line, varies as I_L (current to line) and I_c (current to water column). That due to the other capacitance varies as $I_L I_c$. Since I_L and I_c are both very nearly proportional to voltage, E, the net error power varies as E^2.

The error due to the capacitance between the coil lead to the line and its shield was eliminated by equal-

1. Philip C. Clark and Charles E. Miller, The High Voltage Wattmeter, Pasadena Convention, A. I. E. E., October 1924.

To be presented at the Pacific Coast Convention of the A. I. E. E., Pasadena, Cal., Oct. 13-17, 1924.

izing their potentials. This was done by connecting the shield to the source through a suitable impedance mounted within the instrument shield cage as indicated in Fig. 1. The resistance-inductance ratio of this impedance was made the same as that of the coil and corresponding milliammeter connected to the line. The values of this impedance and the capacitance of lead-to-the-line shield to neutral were then adjusted so as to consume the same voltage as that consumed in the coil and milliammeter by the line charging current.

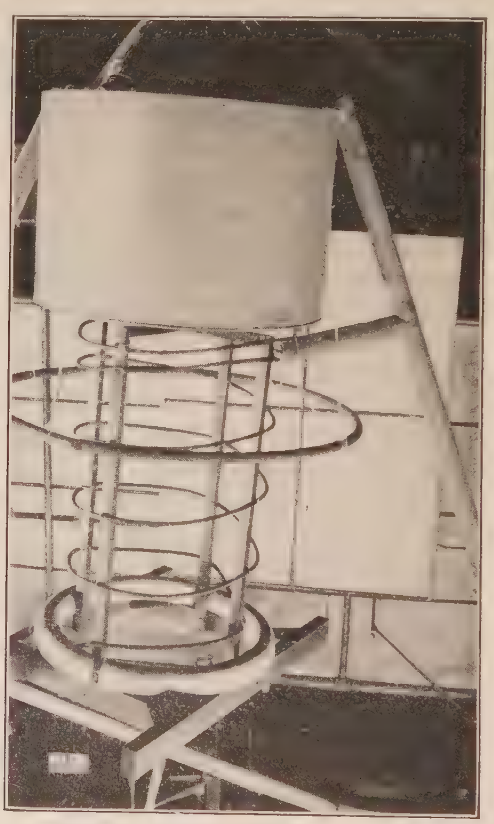


General View of High Voltage Wattmeter Showing Instruments in the Copper Screen Cage, the Water Column Multiplier and the Sphere Gap

The difference of potential then applied to the error-making capacitance was thus brought to zero and the error eliminated.

The companion error due to the capacitance between the voltage coil and milliammeter lead to the water column multiplier and its shield was reduced to a negligible value by a sufficient structural reduction of such capacitance. This was accomplished by making the lengths of the lead and shield a minimum and by using a relatively large diameter (2.5 in.) of shield and correspondingly small diameter of lead (No. 14 B. & S. gage) mounted axially within the shield. Thus arranged, the errors due to the capacitances shunting the wattmeter coils and milliammeters were eliminated.

Further studies of the 1923 wattmeter revealed another difficulty. It came up in the effort to repeat measurements of fixed corona losses. It was found that the values could not be repeated with sufficient agreement. The cause of the difficulty was finally traced to the highly undesirable manner in which the outer shielding water column functioned. The water multiplier and water shielding columns did not, in warming up, form exactly the same temperature patterns. The conductivity of ordinary potable water such as was used, changes rapidly with temperature. Varying potential differences were, therefore, caused between the multiplier and shielding water columns. Corresponding charging currents were, as a consequence, set up through the comparatively large capacitance that existed between the two columns giving rise to corresponding error-powers that would develop



Shielded Water Column Resistance Multiplier for Wattmeter

and vary as the temperature patterns changed. It was found impracticable to maintain equality of such temperature patterns. The shielding water column used in the 1923 wattmeter was, therefore, entirely abandoned.

Another form of water column multiplier was designed and constructed so as to reduce the errors due to capacitance substantially to zero. A quarter-inch air hose was used which allowed shortening the net length to 20 feet or one fourth the length of the hose in

the former column. It was wound on four bakelite strips and formed a helix eighteen inches in diameter and about three feet long. To insure a sufficient flow of water through such a small hose to keep it from overheating, the pressure of the tap water supply was used to force the water through it up into the tank above. In mounting it, the water column was placed as far above the ground as practical, which was about 12 ft. The capacitance of the tank was eliminated by connecting the wattmeter just one turn of hose below the tank, the latter being connected directly to the high-voltage supply. It is true that the water in this section of five feet of hose shunts the wattmeter coil; however, the resistance of this part of the water column was about half a megohm, whereas the total impedance of the wattmeter coil and milliammeter was only 1160 ohms,

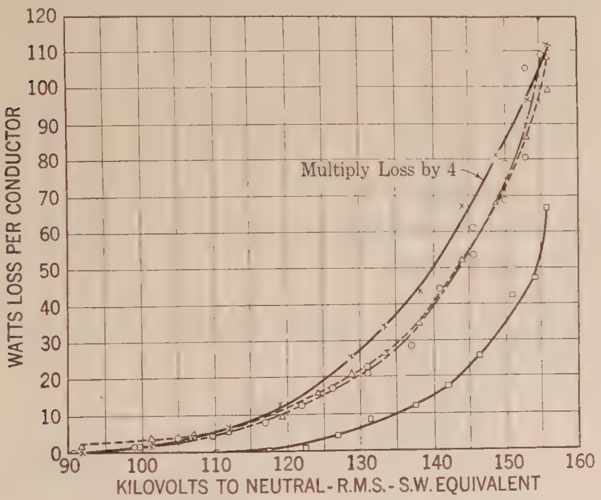


Fig. 2—Corona Loss. Concentric Strand Cable

Diameter 1.008 in., length 231.5 ft.

Curve	×	△	⊡	⊙
Date	3	3	5	22
Barometer	76.327	76.327	76.620	75.743
Temp. °F	54	54	64	62.5
Rel. Humidity	..	68%	20%	51%
Vapor Product	..	0.1935	0.0239	0.1445
Time	11:20 a. m.	4:00 p. m.	10:10 a. m.	3:44 p. m.
Weather	Lt. Rain	Fair	Fair	Fair

so that the error introduced by the connection was negligible. With this arrangement the capacitance of the water column was very small. The tank itself served as a good shield, and only a little additional shielding was found to be necessary. This was accomplished by placing a ring, made out of one-inch metal tubing, around the water column. The ring was suspended from the tank to which it was connected and stood out concentrically from the water column about eight inches. The distribution of the shielding field was further improved by placing another ring at the bottom of the water column, connecting it to the ground wire at the end of the small hose.

When the true power was known to be small, it was found that the shields could be so placed that the wattmeter could be made to give a negative reading. The meaning of this was that the error power through adjustment of the shields could be reversed in sign. From this it followed that if the values of the error powers were known they would furnish a guide to find the positions of the shields whereat the magnitude of the error power would be reduced to zero.

A method was, therefore, developed to segregate the true and error power constituting the corresponding aggregate indicated by the wattmeter as follows: The real power due to a few watts (say 30 to 50) of line corona loss and the error due to the water column multiplier capacitance were held rigidly constant through fixed frequency and crest voltage. The latter was controlled by a sphere gap. By varying the flow of the water in the column, its temperature and thereby its resistance could be changed. In this way I_c (in phase with the voltage) could be varied by any fractional amount. Under these conditions the part of the wattmeter reading due to actual power increased by the same proportionate amount as I_c, while the residual part of the reading due to capacitance error remained constant (independent of I_c). Remembering these facts, with two sets of readings taken at different values of I_c, two simple equations were produced for the equalities of the wattmeter aggregate readings and the sums of the corresponding true and error power portions thereof. By the solution of these equations the value of the error reading was determined. Then, by trial, shielding could be varied until the error became zero.

The Weston wattmeter used in these measurements was a sensitive specially designed instrument. The full scale reading of 1.5 watts would be obtained at 20 per cent power factor with maximum rated current through each coil. The currents to the line and water column resistance multiplier were measured by milliammeters. These three meters were all inclosed in the copper screen cage which was connected to the high-voltage terminal of the transformer. The instruments were read by means of telescopes about six feet distant. The two milliammeters were used in the vertical position and the wattmeter was used in a horizontal position, being read from a platform built above the screen cage.

As a test of the ability of the wattmeter to measure actual power, a special test was devised. A 6000-ohm resistance consisting of two Thomson wattmeter multipliers was inclosed in a cylindrical metal shield with hemispherical ends, one end of the resistance being soldered to the shield and the other end brought out through an insulating bushing. A regular set of readings was taken at some definite sphere gap setting then this resistance of 6000 ohms was inserted in the circuit at the point where the wattmeter lead connects on to the line and another set of readings taken at the same sphere gap setting as before. Knowing the line current and this added resistance, the power absorbed by it could be computed and compared with the increase in

power as shown by the wattmeter. These results checked very well.

As a check on the reliability of the method of separating real and error power by changing the resistance of the water column by diminishing the flow of water, the following test was made: A set of readings was taken at a definite line voltage with the water flowing freely through the hose; the voltage was there held constant and the resistance of the water column decreased by restricting the flow of water. When the current through the water column had reached a predetermined value the meters were again read. The power was computed from the differences of the two wattmeter readings and the two currents through the water column. The resistance was then inserted in the line circuit and the procedure repeated at the same voltage as before. The difference in the power computed from these two tests should be the $I^2 R$ loss in the resistance. The following are the results of these tests at two different voltages:

Line Kv. V_H	I_L	I_c	W	Actual Power*	Mean Value
		No resistance in line			
240	31.9	38.6	0.062		
240	31.3	70.0	0.081	14.7	
240	31.8	38.6	0.058		
240	31.2	70.0	0.078	15.5	15.1 (a)
170	23.1	26.1	0.010		
170	22.8	60.0	0.010	0	
170	23.1	26.1	0.011		
170	22.8	60.0	0.012	.5	.2 (b)
		5989 ohms res. in line			
240	31.6	38.4	0.065		
240	31.0	70.0	0.097	24.7	
240	31.5	38.5	0.065		
240	30.9	70.0	0.093	21.6	23.1 (c)
170	23.0	26.1	0.012		
170	22.7	60.0	0.022	5.1	
170	23.1	26.1	0.013		
170	22.7	60.0	0.022	3.5	4.3 (d)

*Computed from the increase in wattmeter reading produced by the Increase in I_c.

As can be seen from the data, the measured power increased when the resistance was inserted. The amount of power absorbed in the resistance is given by the difference of (a) and (c) for the one voltage and from (b) and (d) for the other voltage. These values are 8.0 watts and 4.1 watts and the loss computed from the resistance and the line current is correspondingly 6.0 watts and 3.1 watts. It was indeed gratifying to know that such small values of power could be measured with fair accuracy at such high voltages and low power factors. The accuracy here was not quite 100 per cent, however, considering the magnitude of the wattmeter reading, and also that the greater part of it was error power, the results are as close as would be expected. It was this test which showed that true power could be separated from error power by the method of changing the water column resistance.

The test was made before the water column had been sufficiently shielded to give correct power from a single set of readings. The shielding was then adjusted until the computed power was the same, irrespective of the resistance of the water column. The following are data of tests in which the power due to corona loss on the line was measured with different currents through the water column:

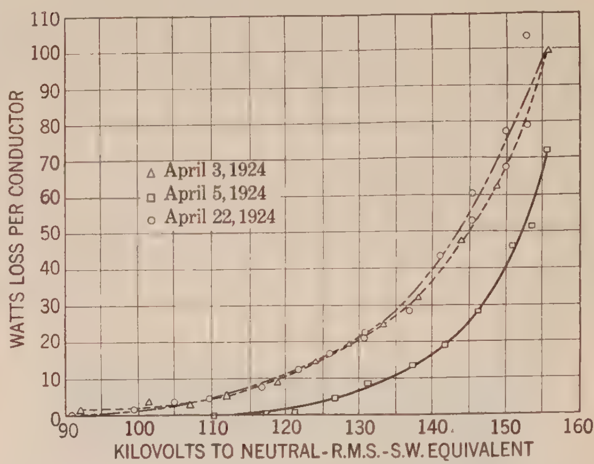


FIG. 3—CORONA LOSS. CONCENTRIC STRAND CABLE
Diameter 1.008 in., length 231.5 ft. Corrected to vapor product of 0.15 and air density of 1.000.

V_H	I_L	I_c	W	Power: By Watt-meter	Power: Computed from $W_2 - W_1$ and $I_{c2} - I_{c1}$
		April 3, Aluminum Con. Cable in Light Rain (I_L held constant)			
190	..	43.5	0.018	8.0	
190	..	70.0	0.028	7.7	7.3 (Water up)
210	..	44.3	0.050	24.0	
210	..	70.0	0.077	23.4	22.4 (Water up)
		April 4, Lock Cable. (Dry)			
210	27.6	49.5	0.0005	0.21	
210	27.6	70.0	0.0005	0.15	0 (Water down)
210	27.6	44.0	0.004	1.9	
210	27.6	70.0	0.006	1.8	1.6 (Water up)
		April 8, Lock Cable. (Dry)			
255	34.1	61.4	0.090	38.0	
244	34.2	70.0	0.103	38.1	39.6 (Water up)

The results were very satisfactory, showing not only that the water column capacitance error power had virtually been eliminated but also that the power loss below visual corona, if any, was extremely small.

The Corona Loss—Crest Voltage Relation at Voltages Upward from Critical Values

The value of the crest voltage in all corona and related actions is controlling.[2] The measured values

2. Harris J. Ryan and Henry H. Henline, The Mechanism of Corona Formation. A. I. E. E. Pasadena Convention, October 1924.

of power are believed to be as accurate as necessary as long as the sphere gap must be used to determine crest voltage. It is only accurate to two per cent, but a two-per-cent change in crest voltage may cause a far greater change in corona loss because of the character of the corona loss-power relation.

The method of test was to set the sphere gap and raise the voltage until the sphere gap sparked over. At that instant the voltmeter, wattmeter, and both milliammeters were read. This procedure was repeated at different sphere gap settings until a sufficient number of values had been obtained. Power was

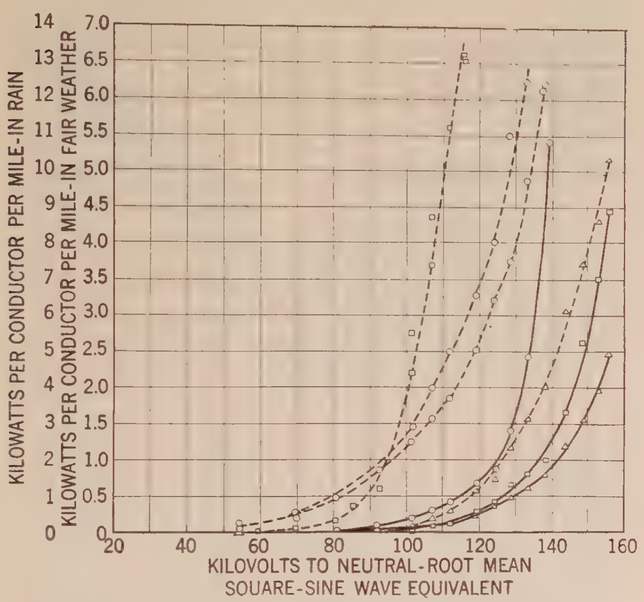


Fig. 4—Corona Loss Plus Insulator Loss

Curve	⊙	⊡	△	⊙	⊡	△
Cable	rope lay	lock wire	conc. str.	rope lay	lock wire	conc. str.
Material	copper	copper	aluminum	copper	copper	aluminum
Diameter	0.91 in.	0.91 in.	1.008 in.	0.91 in.	0.91 in.	1.008 in.
Circular mils	500,000	700,000	806,600	500,000	700,000	806,600
Date	3	3	3	1	1	3
Barometer	30.05 in.	30.05 in.	30.05 in.	29.98 in.	29.98 in.	30.05 in.
Temp. °F.	54	54.5	54	53.5	53.5	54
Rel. humidity	51%	66%	68%	..	..	..
Time	4:45 p.m.	4:20 p.m.	4:00 p.m.	2:20 p.m.	3:00 p.m.	11:20 a.m.
Weather	Clear	Clear	Clear	Lt. rain	Mod rain	Lt. rain
Spacing	18′	17′	17′	18′	17′	17′

computed from the meter readings by the following formula:

$$P = \frac{W_m \dfrac{V_m \times 1000}{2}}{4931 \times 0.001\, I_c}$$

Where W_m is wattmeter reading, in watts, V_m is voltmeter reading in volts, I_c is current to the water column in milliamperes, 4931 is the wattmeter constant. P is the power in watts, and the other constants take care of voltage to neutral, and the proper units. I_L does not enter into the computation of power but was measured for other purposes.

The cables used in the tests were rope-lay, concentric strand and lock wire. The rope-lay and concentric strand cables are familiar to everyone. The lock wire cable is similar to that used on aerial tramways and has a smooth exterior.

The curves of corona loss in Fig. 4, show that the loss is less than that found by most previous investigators. Corona loss starts at approximately the visual corona voltage and the loss below this point, if any, is negligible. The rope-lay cable had a much rougher surface than the other cables and therefore might be expected to have a larger loss. At 130 kv. to neutral, the loss in fair weather was from 1.4 to 1.6 kw. per conductor per mile. At 120 kv. the loss was from 0.5 to 0.7 kw. per conductor per mile. In rain, the loss at 130 kv. is 9.5 kw. per conductor per mile. The loss at 120 kv. is 6.0 kw. per conductor per mile or twelve times the fair weather loss. The loss in rain starts at below 50 kv. to neutral while the loss in fair weather starts at from 70 to 90 kv. to neutral.

In fair weather the loss on the lock wire cable is very low. At 140 kv. to neutral the loss is from 0.35 to 0.9 kw. per conductor per mile while at 120 kv. the loss is only from 0.02 to 0.25 kw. per conductor per mile. In rain the loss is much greater. At 110 kv. to neutral the loss is 9.5 kw. per conductor per mile or nearly 200 times the fair weather loss for the same voltage.

The loss on the aluminum concentric strand cable is much less than would be accounted for by the fact that it is somewhat larger in diameter than the others. In dry weather at 140 kv. to neutral the loss is from 0.9 to 1.25 kw. per conductor per mile. At 120 kv. to neutral the loss is from 0.15 to 0.30 kw. per conductor per mile in fair weather. In rain the loss is about 4.5 kw. per conductor per mile at 140 kv. and about 1.2 kw. per conductor per mile at 120 kv. to neutral. This means that the wet weather loss is about four times the fair weather loss through a specified range of voltage.

From an inspection of the curves shown in Figs. 2 and 3, it is seen that the amount of moisture in the air has a great influence on corona losses of this order. Mershon[3] found that corona loss was a function of the vapor product. He defined vapor product as the product of the relative humidity in per cent and the vapor pressure in inches of mercury. Approximate equations of Mershon's corona loss vapor product curves were obtained and by them our results were reduced to the same vapor product. As can be seen by the comparison of Fig. 2 and Fig. 3, the curves of the concentric strand cable were somewhat closer together after correcting for vapor product. Although corona loss may vary as a function of the vapor product, the results of these tests do not follow Mershon's curves. Mershon found that the vapor product affected the "critical point" or point where the law of the curve changes. The critical point on his curves corresponds to the voltage

3. Mershon. High Voltage Test. Trans. A. I. E. E., Vol. XXVII, p. 845.

where corona loss starts on our curves or approximately visual corona voltage.

The moisture in the atmosphere seems to affect the starting point of corona and the part corona loss, but it has little effect on the full corona loss. From the results of present tests it would seem that not only was the starting point of the curve shifted but the shape of the curve was changed by the amount of moisture in the air. When these values of loss are plotted on semi-logarithmic paper (Fig. 5) they seem to indicate the existence of three laws since three intersecting straight lines are formed. The slopes of the upper and lower straight lines are practically independent of the

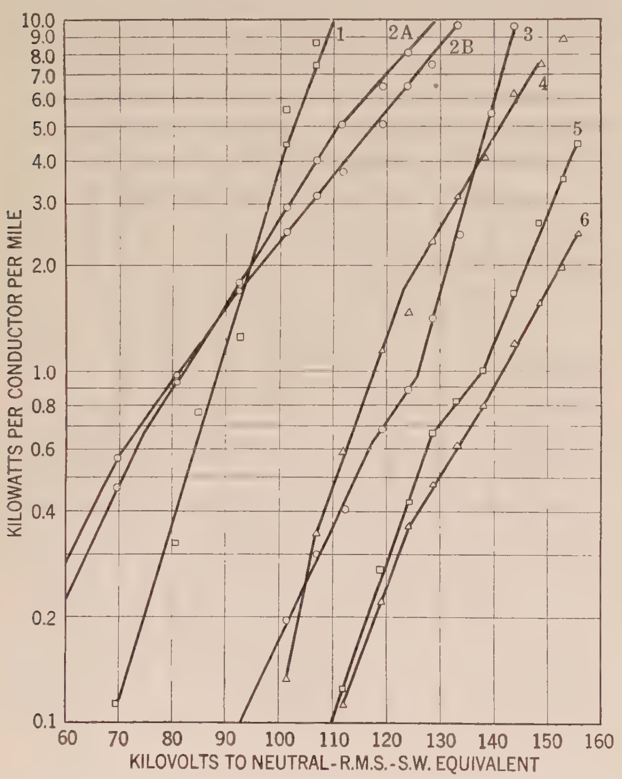


Fig. 5—Corona Loss Plus Insulator Loss

1. Lock Wire—Rain
2. A. Rope Lay—Rain
3. B. Rope Lay—Fair
4. Concentric Strand—Rain
5. Lock Wire—Fair
6. Concentric Strand—Fair

humidity, but the slope of the middle line seems to depend on the amount of moisture in the air. It has been suggested that these three lines refer to brushes from clamps, part corona and full corona.

Insulator Losses

Insulator losses on a ten-unit string were measured in the laboratory building at 150 kv. to neutral. For cap and pin insulators with skirts the loss was about 7 watts dry and dusty, 5 watts dry and clean, 4¼ watts wet on top, 4¾ watts when sprayed from top; 9 watts when wet and dirty and 450 watts when wet all over. At 150 kv. the loss on a ten-unit string of core-and-tine insulators was found to be about 10.25 watts dry and clean; 10 watts when sprayed from top and 150 watts when wet all over.

Through corona loss tests on the laboratory yard tower line by difference between corona loss with one supporting insulator string excluded and again included in the wattmeter circuit, the loss on a 9-unit string

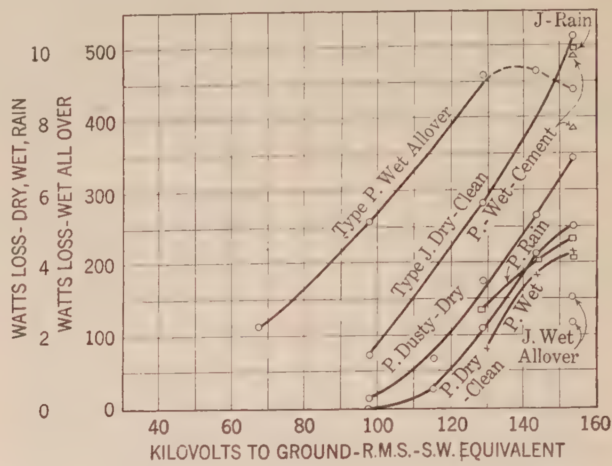


Fig. 6—Insulator Losses on 10-Unit String

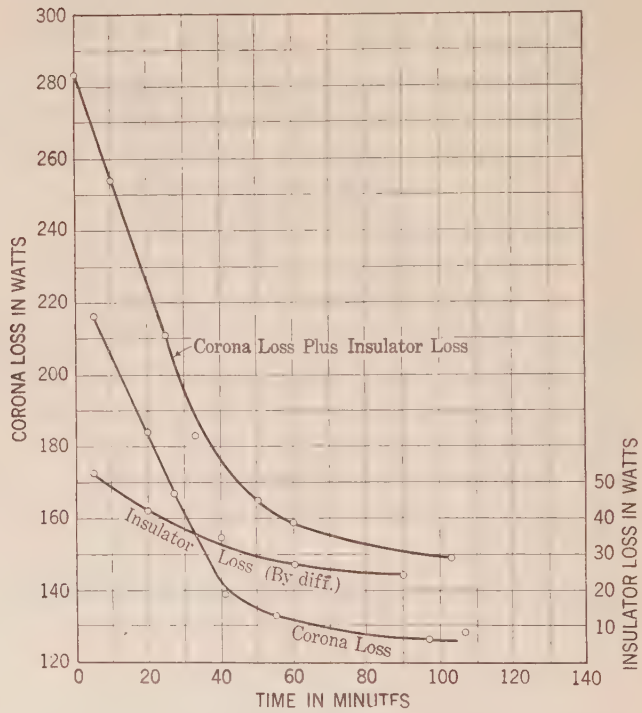


Fig. 7—Corona and Insulator Losses

Lock Wire Cable. Temp. 57 deg. to 62 deg. fahr. Barometer 29.94 in. Relative Humidity 77 to 67 per cent. Time 9:10 to 11 a. m., April 12, 1924. High Fog—to clear 151.3—150.0 kv.

of cap and pin-type insulators with skirts was found to be about 50 watts at 150 kv. when wet with dew. By the same method the loss on the same string of insulators was found to be 20 watts at 135 kv. in the rain.

From these results it is seen that insulator losses

in dry weather are negligible. In light rains the loss is still low but in heavy rains accompanied by wind the insulator losses may become very high. From the few observations made it seems that the loss when dew is on the insulators is greater than during light rains.

Brush Losses

Measurements were made of the power loss-voltage relation for a variety of corona brushes, singly or in

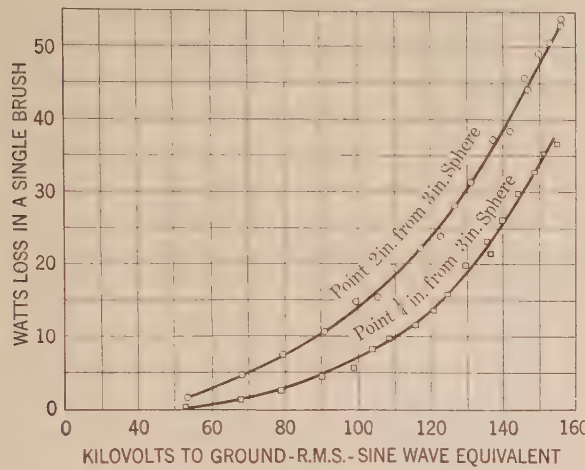


Fig. 8—Brush Losses

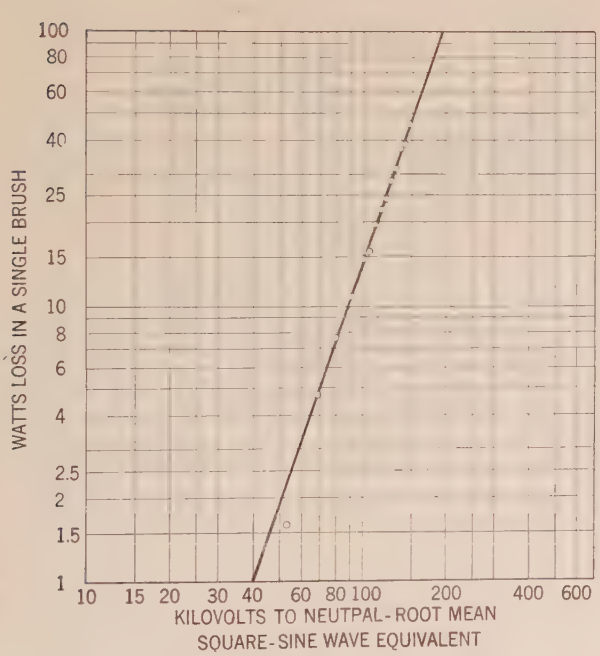


Fig. 9—Power Loss in a Single Brush

Barometer 29.89 in. Dry Bulb Temperature 51 deg. fahr. Wet Bulb Temperature 52 deg. fahr.

multiples. When the number of brushes was small, 1 to 6, a wire was run out from the high-voltage source terminal through the wattmeter, a distance, generally, of about six feet. With its concentric shield, 2.5 inches in diameter, it was supported horizontally on insulators about four feet up from the concrete floor. The tubular shield was terminated with a three-inch sphere. The lead wire was extended a convenient distance beyond the spherical end of the shield as specified later. From it from one to six points were mounted from which to set up brushes.

When the brushes to be formed were many (from a few to 500) the requisite points from which to form them

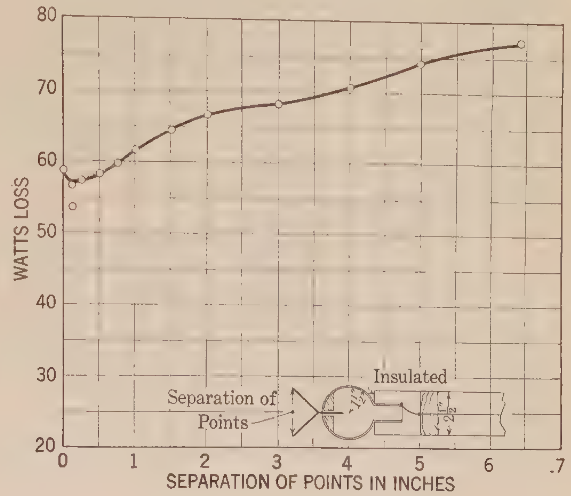


Fig. 10—Brush Loss

2 Points in a "V" Temp. 70 deg. fahr. Barometer 29.96 in. 154.0 kv. Relative Humidity 20 per cent. Points 3 in. from 3 in. Sphere.

were provided by cementing the heads of small (*one-quarter-inch*) tacks to the surfaces of metal tubes having diameters and lengths to be specified later. Both ends of the tubes were suitably shielded. Thus arranged, the wattmeter measured only the losses set up from the points as desired.

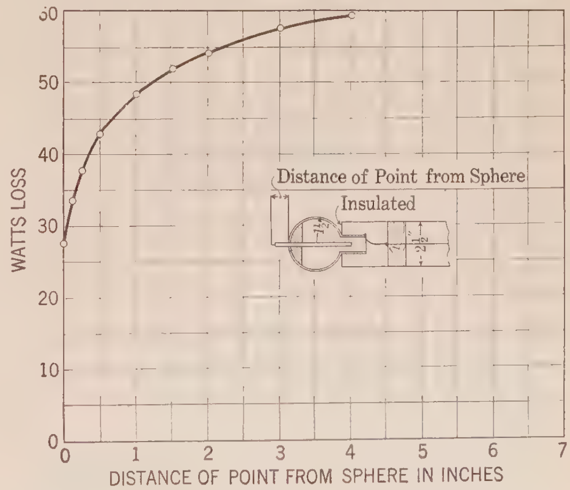


Fig. 11—Effect of Point Length on Brush Loss

Temp. 70 deg. fahr. Barometer 29.94 in. 154.3 kv. Relative Humidity 33 per cent.

The loss from a brush from the end of a wire or rod is much larger than the loss from a single brush on a line conductor cable. The brushes on a cable crowd each other. It is not surprising, therefore, that the loss per brush is less when there are more brushes.

The curve of a single brush located on logarithmic paper by losses and corresponding voltages (Fig. 9)

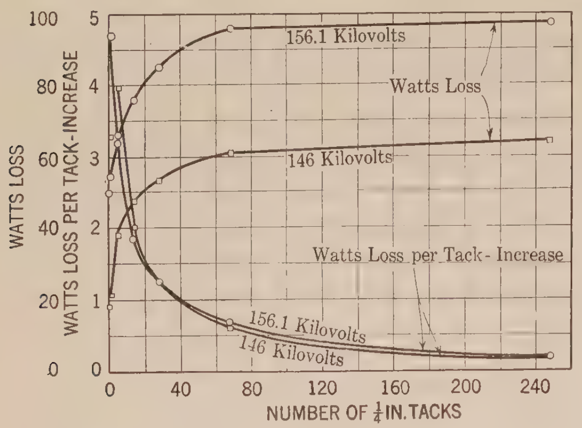


FIG. 12—EFFECT OF TACKS ON CORONA LOSS FROM CONDUCTORS
Length 2 ft. 3 in. Aluminum Tube Diameter 17/32 in.

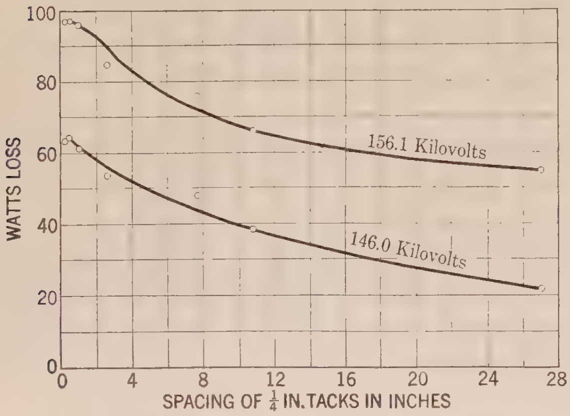


FIG. 13—EFFECT OF SHIELDING ON BRUSH LOSS FROM CONDUCTORS
Length 2 ft. 3 in. Aluminum Tube Diameter 17/32 in.

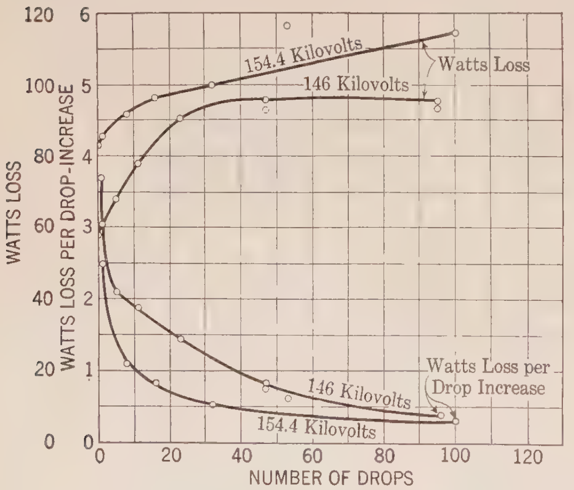


FIG. 14—EFFECT OF WATER DROPS ON CORONA LOSS FROM CONDUCTORS
Length 6 ft. Brass Tube Diameter ½ in.

indicates that the brush loss in the particular circumstances varies over a wide range with the cube of the voltage. For other brush losses the curve seems to be similar but the variation of loss is not as the cube but as some other power of the voltage.

The curve of Fig. 10 shows clearly the shielding effect of one point upon another. The curve of Fig. 11 likewise shows the shielding effect of the sphere from which the point projects.

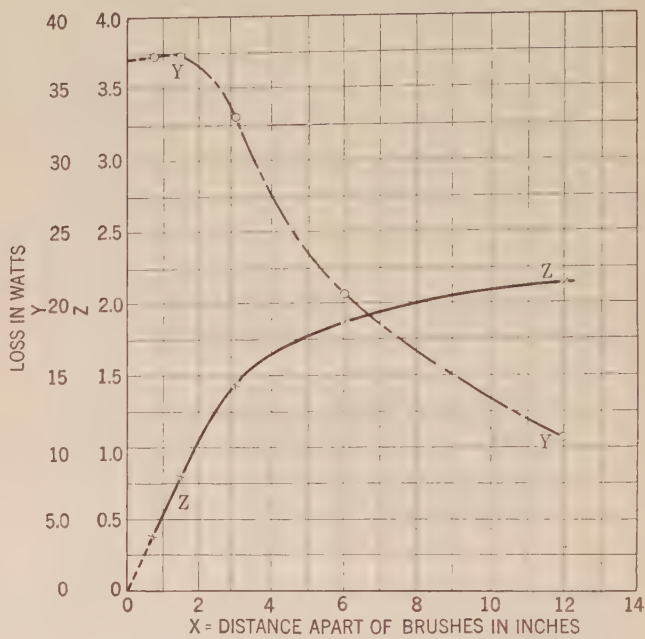


FIG. 15—CORONA LOSS TESTS
Effect of Mutual Shielding. Loss due to Brushes on ½ in. Polished Brass Tube 6 ft. long at 138 kv. R. M. S. to Neutral. Brushes formed on Water Drops. Dry Tube Loss—57.5 W. $Z-Z$ Loss per Brush. $Y-Y$ Loss due to all Brushes on 6 ft. Length. $Y = \left(\frac{72}{x} - 1\right) Z$

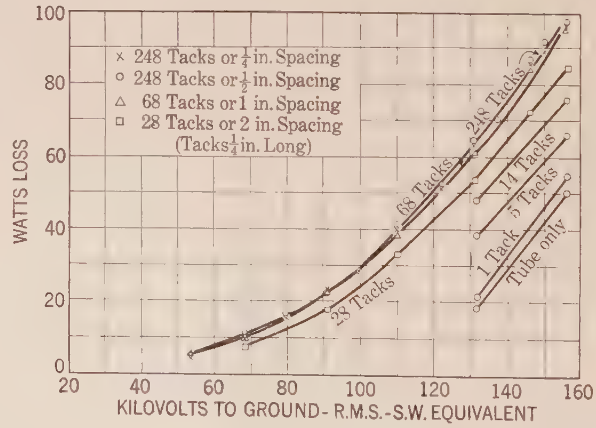


FIG. 16—EFFECT OF SURFACE ON CORONA LOSS FROM ROD
Diameter 17/32 in. Length 2 ft. 3 in.

Figs. 12 to 15 show the effect of surface irregularity and of water drops on corona loss as well as the shielding effect of the brushes from water drops and tacks. Figs. 16 and 17 show the effect of surface roughness on corona loss. Tacks were equally spaced on a rod and the corresponding curves were obtained as shown.

Loss from Conductors as Affected by the Surface

The curves of loss from a brass tube are especially interesting because they are virtually straight lines. The loss with a polished tube was considerably lower than it was when coated with soot from a candle flame. The loss from the tube when its surface carried its natural tarnish was still higher than when soot covered.

It is interesting to note that the loss from a section of the cable from the Big Creek Line covered with a nautral deposit of carbon was three fourths that from a section of new cable under the same conditions.

From the curves of brush and corona losses as affected by surface conditions it would seem that the loss increases as the number of projections on the surfaces up to certain points and then remain practically constant or they may decrease slightly as the number of projections is greatly increased. This may be understood from the brush loss curves. The brushes stretch out quite a distance into the air around them and therefore are affected by what is taking place near them. When they are too close together the loss per brush will be decreased, but since there must be more brushes to accomplish this the total loss will be more. There is a final limit where the loss per brush decreases faster than the number of brushes increases and therefore the total loss becomes less. This explains the distribution of brushes on a conductor. Where opportunity for the formation of brushes is favorable they will form only so close together that their field will not decrease the total loss. When they are too close together their number is decreased and the total loss is again increased to the maximum. In other words, brush formation stabilizes toward the production of maximum loss.

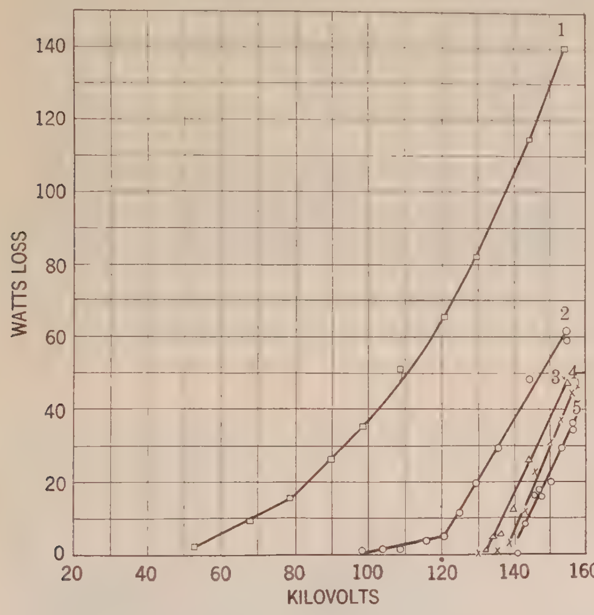


Fig. 17—Effect of Surface on Corena Loss

Curve.......	1	2	3	4	5
Conductor...	Al. tube	Al. tube	Brass tube	Brass tube	Brass tube
Surface......	Wet string	Dry string	Natural	Soot coated	Polished
Length......	5 ft.	5 ft.	5 ft.	5 ft.	5 ft.
Diameter....	17/32in. 5/8in.	17/32in. 5/8in.	5/8 in.	5/8 in.	5/8 in.
To ground....	3 ft. 7 in.	3 ft. 7 in.	3 ft. 6 in.	3 ft. 9 in.	3 ft. 9 in.
Barometer...	29.99 in.	29.99 in.	29.99 in.	30.08 in.	30.08 in.
Temp. °F....	69 deg.	69 deg.	69 deg.	64 deg.	64 deg.
Rel. humidity	39%	39%	39%	45%	45%

Conclusions

1. It has been found practicable to separate true and error power.

2. The power loss from transmission conductors below visual corona, if there is such a loss, is extremely small.

3. Humidity is a "part" or "local" corona loss factor.

4. Losses on dry insulators are small; when completely wet may be relatively high.

5. Rain increases corona losses considerably, the amount of such increase depending upon the type of conductor.

6. For a given length of conductor with points on it, the loss per brush decreases with the number of brushes and the total loss increases with the number of brushes up to a certain value and then remains constant or nearly so.

Acknowledgments

Though the names of the authors will usually be associated with the results of these studies, when credit is to be conferred, several others must be considered. Prof. Ryan, always inspiring, has been a very dependable source of ideas for the solution of problems. Prof. Henline has greatly assisted, not only in the operation of equipment but in many other ways such as pointing out errors in methods of measurement. It is with great pleasure that we acknowledge this and express our deep appreciation to them as well as to others who have been involved in the work.

CHANGE OF DATE OF RADIO CONFERENCE

Announcement was made at the Department of Commerce on September 16, that the date for the Third National Radio Conference has been set for Monday, October 6th, instead of September 30th, as was announced in the September Journal.

The first session will be held at the Department of Commerce building at 8 p. m., on October 6th, and will be opened with a statement by Secretary Hoover outlining the aims and purposes of the conference. This will be the third radio conference of national scope called by Mr. Hoover, the others having been held in February, 1922, and March, 1923. The proceedings will be public and all persons who have suggestions to make in regard to the subjects before the Conference will have ample opportunity to express their views. The Conference will consider and make recommendations regarding the allocation of frequencies or wavelengths to the various radio services, probably giving particular attention to broadcasting.

High-Voltage Impregnated Paper Cables

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and

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Review of the Subject.—*A limit of carrying capacity was reached in high voltage cables due to high dielectric losses, and in order to overcome this limitation, science had to be called upon to introduce measurements and tests to control this quality. The exact experience gained in the development of these tests by scientific men working in cooperation with the men of practical experience enabled the cable industry to attack the next limitation that confronted it, namely, dielectric strength. The industry has already made considerable progress, and the present problem is the complete elimination of occluded air and vapor from the insulation. Air films have been regarded as causes of low dielectric strength, due to ionization of the air and consequent formation of hot spots. It is advanced, herein, that a more useful conception of the danger of air films, is that they promote internal surface leakage. It has also been generally believed that air films can be detected by the slope of the voltage power-factor characteristic. It is contended herein that such is not the case. It is pointed out that the foundation for future developments has been laid by the equipment and organization of American cable manufacturing plants for accurate quality control by continual testing of raw and process materials.*

Few tasks are now facing the electrical engineer in which more general interest is being taken than the development of cables for higher voltages.

For many years, cables have been operating with a very fair degree of success at tensions of 19 to 25 kv. When attempts were made to make cables for somewhat higher voltages, dimensional limitations prevented the retention of the potential gradients that time had proved to be reliable and it became necessary to subject the insulation to higher stresses. It was found that at these stresses general weaknesses would develop and weak spots would be revealed in the insulation, which would not show at the lower stresses.

The first step was to reduce the dielectric loss, then to use a compound that would not be too stiff at low temperatures, and then to control the dielectric qualities of the paper. When this was accomplished, factory failures were practically eliminated and field failures greatly reduced.

Analysis of the latter showed three things: first, that at high stresses all mechanical defects, arising either in manufacture or subsequent handling, reveal themselves sooner or later; second, that air films, under certain circumstances may be the cause, and third, that operating conditions with special reference to potential surges have to be more carefully controlled.

It therefore became necessary for the manufacturers to establish a new standard of mechanical construction and to carry out elaborate researches on the elimination of air films. Much progress has been made in both of these matters during the past few years, and cables are now being made having unprecedented dielectric strengths, figures as high as 200 kv. per cm. (average stress) having been attained on single-conductor cables, while three-conductor cables for 25,000 volts and higher cannot be broken down because no way has yet been found to make the ends immune from flashing or failure at the crotch. But more important than this, these cables have unprecedented ability to withstand high stresses for long periods without deterioration.

Presented at the Annual Convention of the A. I. E. E., Edgewater Beach, Chicago, Ill., June 23-27, 1924.

These results have been obtained by the careful control of materials and processes. This paper is devoted principally to a description of the principal control tests developed by an American cable manufacturer.

Four types of experimental samples were used for the research work required to ascertain the crucial properties which must be controlled and their optimum values.

1st. Impregnated sheets of paper (usually three deep) were tested between A. S. T. M. electrodes as shown in Fig. 1. Such flat samples are inexpensive, are quickly prepared and eliminate all structural complications, *i. e.*, they enable the material to be tested without introducing any element based on the mechanical make-up of a cable. Thousands of tests on samples of this character were made.

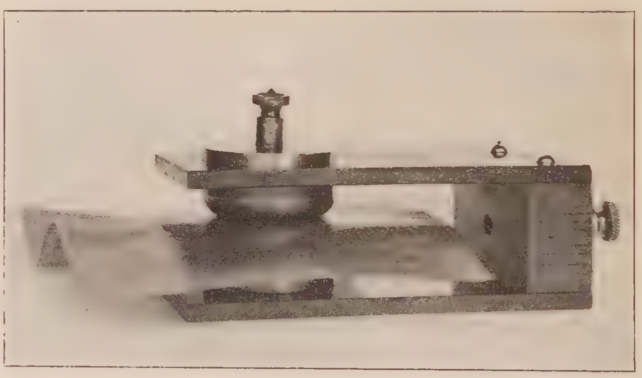

Fig. 1—A. S. T. M. Electrodes as Applied to the Testing of Flat Samples of Treated Paper

2nd. Samples of cable six in. long, the drying and impregnation of which could be carried out in a miniature apparatus are shown in Fig. 2.

3rd. Samples of cable without sheaths, about 15 in. long were treated with different kinds of impregnating compounds. Tin foil was then applied to the middle part of the sample to serve as a sheath and rolls of insulation were applied at the ends, as shown in Fig. 3 to provide a long leakage path and a barrier to prevent a flashover of the test voltage. The samples were tested with a voltage two to three times the normal

operating voltage for two hundred hours. Periodically, the samples were tested for dielectric loss or power factor.

4th. Samples of cables, with sheaths, about 15 ft. long, dried and impregnated in a small tank and tested with their ends in oil are shown in Fig. 4 for momentary dielectric breakdown, or with their ends taped with asbestos for prolonged voltage applications. During the years 1922 and 1923, 526 special experimental lengths of this kind were made and tested.

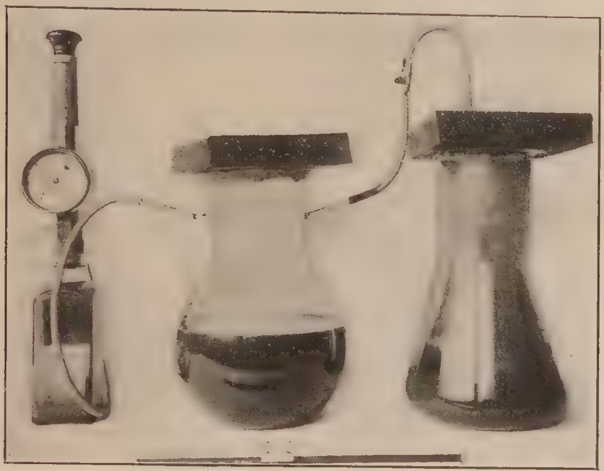

Fig. 2—Miniature Apparatus for Drying and Impregnating Cable

Some of the variables which were altered were as follows: *Oil*: Viscosity, resistivity, dielectric strength, flow point, susceptibility to oxidation, influence of rosin and other substances.

Paper: Amount of manila fiber, amount of rag stock, amount of jute stock, amount of wood stock, hydration, density, thickness, oil reluctance, tearing strength along and across grain.

Taping: Width of tape, tightness, lap.

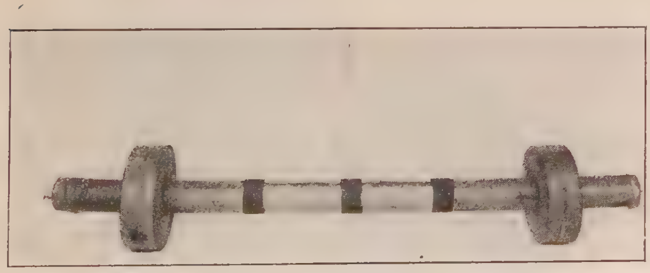

Fig. 3—Sample of Cable 15 In. Long for Artificial Aging

Drying: Time, proportion of time in air and in vacuum, temperature.

Impregnating: Time, temperature, vacuum, pressure maintenance, and freshness of oil.

Cooling: Time, final temperature, interval between tank and press, medium for cooling cable, *i. e.*, oil or air.

This list by no means exhausts all the variables and it should be clearly understood that the optimum value of each variable is not a constant, but depends upon the combination of other variables associated with it.

The experimental determination of the optimum cable, assuming five values of each variable to be tried, would therefore involve the making and testing of at least thirty-six billion kinds of experimental cables.

The reduction of this number to a workable series of tests can only be effected by the application of theory. A theoretical understanding of cable manufacture would include thermodynamics, mechanics, oil-chemistry, paper-chemistry, and electrophysics.

The 15-ft. samples were also tested or examined for some or all of the following qualities: dielectric strength, dielectric loss, ionization, freedom from air films and general appearance. Many were tested for dielectric loss both before and after an aging test at about 2½ times normal working stress.

These tests gave a large amount of valuable data but the most surprising thing learned was that most of the

Fig. 4—Samples of Cable 15 Ft. Long Being Tested for Momentary Dielectric Breakdown

variables could be altered over a considerable range without essentially altering the quality of the cable. On the other hand, quality was found to be very sensitive to a few of the variables.

Practical advantage was taken of the information gained in these four series of tests, to establish a system of quality control based on careful regulation of those variables to which cable quality was found to be most sensitive.

The remainder of this paper is devoted principally to a description of these essential tests.

Raw Material Control

There is probably no phase of the manufacture of impregnated paper cables more important than the control of quality of the raw materials.

The essential tests on paper are as follows:

1. Dielectric strength when impregnated.
2. Tearing strength.
3. Folding endurance.
4. Air permeability, *i. e.*, compactness of fibers.
5. Oil permeability.

Dielectric strength is measured on three sheets, 10 by 16 in., dried by heating at 105 deg. cent. for 16 hr. and impregnated in standard compound for two hours at 80 deg. cent. Tests were made with a transformer at 60 cycles, using the A. S. T. M. standard electrodes shown in Fig. 1. Three sheets in series are tested at a time and 10 breakdown values are obtained on each series of sheets. A blind sample, taken from a roll of paper which was found to be very uniform, is run with each test. Errors due to differences in impregnating are eliminated by impregnating the test samples and blind sample together and expressing the results on the former in terms of those obtained on the latter. The distance between electrodes being dependent upon the thickness of both paper and oil films is, unfortunately, not strictly comparable from test to test, as it is impracticable to control the relative thickness of these two elements. Furthermore, due to the high heat conductivity of the electrodes, the breakdown voltages should be compared on the basis of the square roots of the thickness. In spite of these difficulties, the test has proven valuable for control purposes as indicated by a record for one year as shown in Fig. 5.

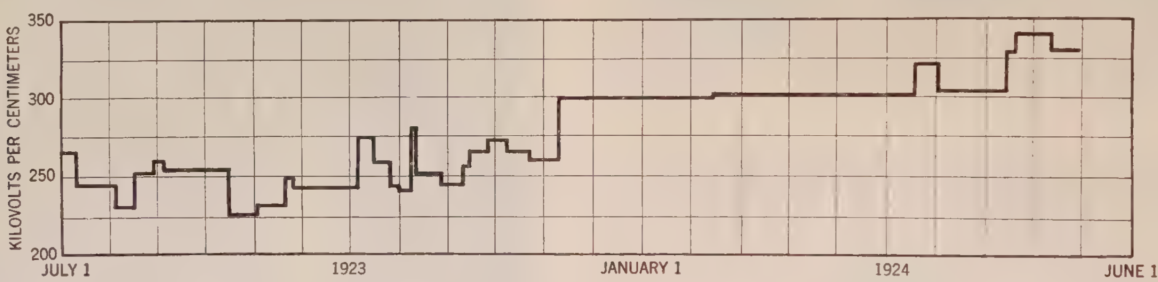

Fig. 5—Typical Control Chart. This Shows the Dielectric Strength of Impregnated Paper

Tearing strength is measured by an Elmendorf machine as described in the Transactions of the A. I. E. E., 1921, Vol. XL, page 143. This instrument measures the energy required to tear a given length of paper. It is shown in Fig. 6.

Folding endurance is measured with the M. I. T. tester shown in Fig. 7. This apparatus holds a strip of paper at approximately constant tension (usually one kg-m.) and folds it over steel edges of standard curvature (0.03 in. diameter) through an angle of about 120 deg. on each side of the straight position.

Density, as it is improperly called, meaning the compactness of fibers, is measured by a Gurley Densometer, Fig. 8, an instrument that measures the number of seconds required for 100 cu. cm. of air to be forced through one sq. in. of paper under a pressure of 570 g.[1]

All physical tests on paper are made in a room kept at a standard humidity of 65 per cent by means of a Bahnson humidifier.

Oil permeability is measured by noting the time required for oil of standard viscosity to make its appearance through a single sheet. The test suggested by Dr. H. H. Brown is made by shaping the paper into a rectangle about 3 by 5 cm. with turned-up edges, and floating it on a dish of oil, as shown in Fig. 9.

The essential tests on oil are as follows:

1. Dielectric strength.
2. Resistivity.
3. Viscosity.
4. Hardness.
5. Solidifying point.
6. Some cable manufacturers test the oil for power factor.

Dielectric strength is measured between electrodes one in. in diameter and 1/10 in. apart at 85 deg. cent. using 60-cycle voltage. The apparatus is shown in Fig. 10. The results are liable to be quite erratic and the average of at least five readings must be taken for each test.

Resistivity is measured by galvanometer method using a cell, Fig. 11, with electrodes of 56 sq. cm. area and 0.5 mm. apart, as described in Transactions of the A. I. E. E. 1922, Vol. XLI, page 569. The results vary over a wide range but if care be taken in making measurements, fairly close checks may be obtained on successive tests. Care must be taken to avoid con-

1. It was pointed out by the authors in an Institute paper that impregnated paper insulation is virtually oil insulation improved electrically by the interposition of barriers to break up circulation and ionic migration.

This conception suggested that variations of dielectric strength might be due to variations in the baffling effect of the paper and an attempt was therefore made to find a measure of this effect. Such a measure was finally found by the authors, in collaboration with Dr. H. H. Brown, in the readings of the Gurley Densometer, an apparatus which measures the compactness of the paper fibers by the permeability of the paper to air under pressure.

Control of the air permeability or density, as its reciprocal is erroneously called, led both to a general raising of the dielectric strength level and in great measure to its equalization at that level.

tamination of the specimens and apparatus by oxygen, sweat, condensed moisture and dirt.

Viscosity is measured with a Saybolt Universal Viscosimeter, Fig. 12. The specimen is placed in an

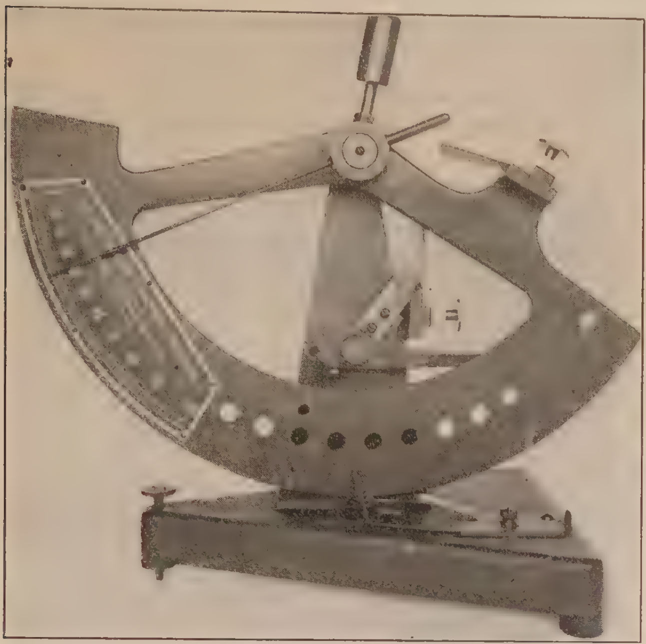

Fig. 6—Elmendorf Paper Tester Used to Test the Tearing Strength of Paper

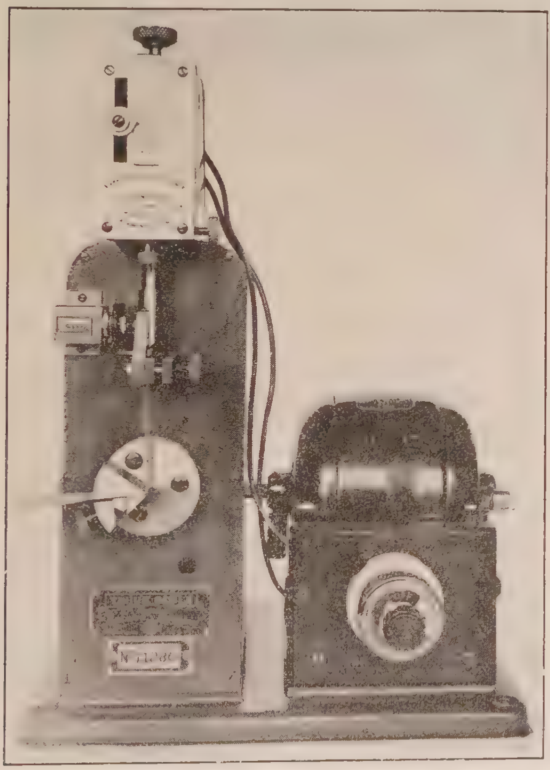

Fig. 7—M. I. T. Folding Endurance Machine

inner receptacle where it is kept at the desired temperature, usually 210 deg. fahr., (99 deg. cent.) by means of oil kept at about 216 deg. fahr. (102 deg. cent.) in the outer bath. The number of seconds required for 60 cu. cm. of compound to pass through a standard orifice is the viscosity. Measurement of hardness have not been developed to a point that justifies a description.

The solidifying point is measured by putting about 10 or 15 cu. cm. of molten compound into a porcelain crucible and stirring with a thermometer while it cools until it is just hard enough not to pour. The temperature is noted and recorded as the solidifying point.

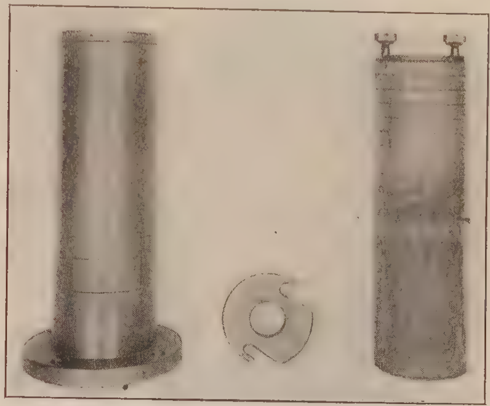

Fig. 8—The Gurley Densometer for Measuring the Air Permeability of Paper

Fig. 9—Oil Permeability is Measured by Floating the Paper Boat on Oil and Noting the Time for the Oil to Penetrate through the Paper

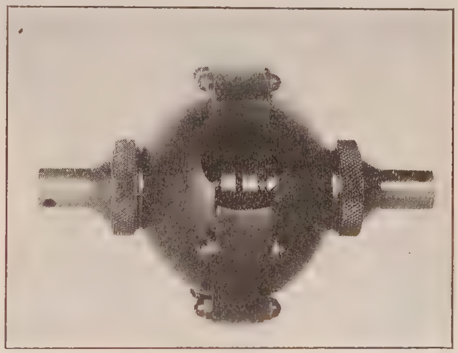

Fig. 10—A. S. T. M. Standard Gap for Testing the Dielectric Strength of Oil

Process Control

Completion of drying is ascertained either by capacity tests made with a 60-cycle a-c. bridge, a capacity meter, or by dielectric loss tests. A typical drying curve is shown in Fig. 13.

The quality of the oil is controlled by tests of resistivity, dielectric strength and viscosity, similar to those described under tests of raw materials.

The impregnated paper on or from cables is tested for

folding endurance, density, saturation and dielectric strength. Saturation is determined by extraction with carbon tetrachloride in the syphon extraction flask shown in Fig. 14. This gives the ratio of oil to paper on a three-in. sample of cable. The test is supplemented by visual inspection of samples several feet long which are stripped tape by tape and examined for surface oil throughout. Research work is under way to find a better check upon saturation.

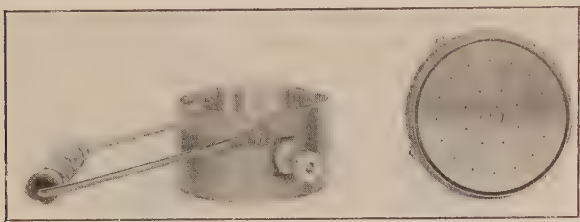

Fig. 11—Cell for Measuring Resistivity of Oil

Fig. 12—Saybolt Universal Viscosimeter

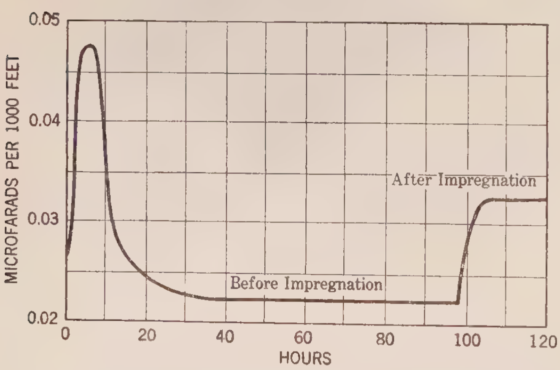

Fig. 13—Drying of Cable Indicated by Capacity Measurements

A number of sections 15 ft. long is taken every week from commercial lengths and tested to failure with 60-cycle voltage. A considerable proportion of these lengths is tested for dielectric loss by the compensated wattmeter method (Pender's Handbook, 1922, page 865). Readings are taken at several voltages to determine the so-called ionization characteristic of the cable in order to collect data on this subject.

Periodic aging tests are made with the 15-ft. samples described above. The usual test is at 2½ times normal working voltage, and the criterion is the chemical stability of the oil.

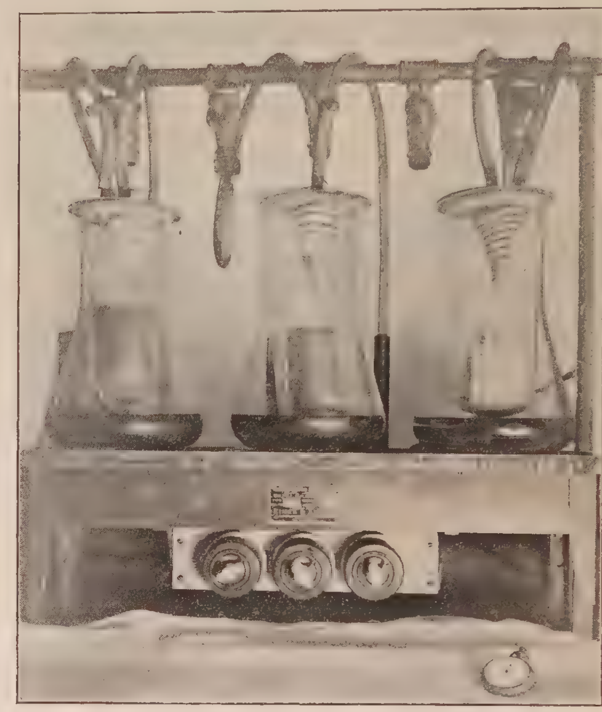

Fig. 14—Extraction Apparatus Used in Determining the Ratio of the Weight of Impregnating Compound to That of Paper

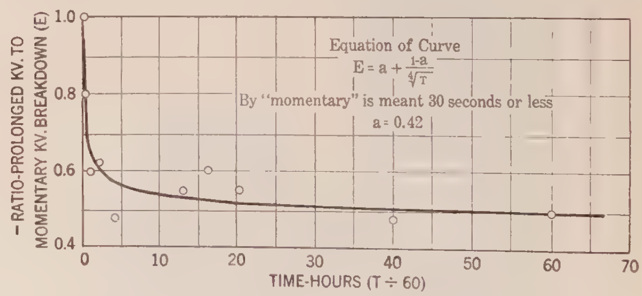

Fig. 15—Time Lag of Paper-Insulated Cables

Several sections per week of the same length are submitted to the bending test, broken down with high voltage and examined for tears.[2]

A few 15-ft. sections have also been tested to destruction with prolonged voltage applications to determine

2. It is of interest to note that while European specifications often call for no torn tapes, the criterion is usually the dielectric strength and not a visual examination as in America.

the time lag of impregnated paper insulation as it applies to electric cables. The dots in Fig. 15 are the data obtained from these tests, whereas the curve is the locus of the following equation given by F. W. Peek, G. E. *Review*, November 1915, and V. M. Montsinger, JOUR. A. I. E. E., Feb. 1924, page 146.

$$E = a + \frac{1 - a}{\sqrt[4]{T}}$$

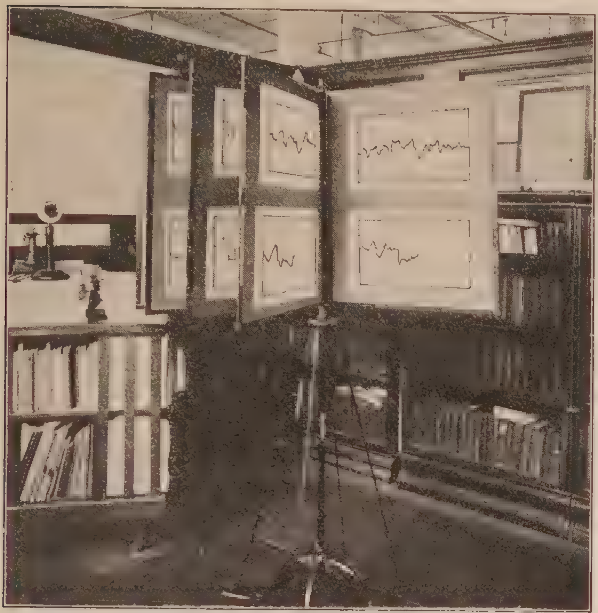

FIG. 16—CONTROL CHARTS

Where

E = the ratio of prolonged breakdown voltage to momentary breakdown voltage. The momentary breakdown voltage is that which causes breakdown in 30 sec. or less.

T = time in minutes.

a = a constant for a given type of cable.

The value of a computed from the breakdown data is 0.42 for these cables. If the value 0.42 is substituted for a in the equation and T made infinite, it would seem that these cables would withstand continuously a voltage equal to 42 per cent of the momentary breakdown voltage. We know, however, from experience that this condition cannot be fulfilled in practise. It follows, therefore, that the equation should be used only for values of T within certain limits. The reason for this limitation, is, perhaps, that other factors of a deteriorating nature enter into action as time goes on.[3]

There are other tests to control processes and materials which cannot be discussed at the present time, but which contribute materially to the results.

The data from all these tests are plotted on charts (Fig. 16) so that the tendency of every characteristic can be noted day by day. One effect has been to reduce the number of high-tension cable failures on factory test, to a negligible number. This saving effected has paid many times over for the cost of the research work upon which it was based.

This work has furthermore, laid the foundation upon which future developments for higher voltages must depend.

Appendix I.

COMPOUNDS WITH AND WITHOUT ROSIN

The American manufacturers were led to abandon rosin largely because of its chemical instability at the temperatures at which American cables are operated. The lower temperatures at which European cables are used, made this consideration comparatively unimportant to them and they probably made their decision on the basis of the greater surface tension between paper and the cylinder oil rosin mixture.

The addition of rosin to a petrolatum or a mineral oil lowers its electric resistivity and various percentages of rosin have an interesting effect upon the resistivity of petrolatum at different temperatures, Fig. 17A

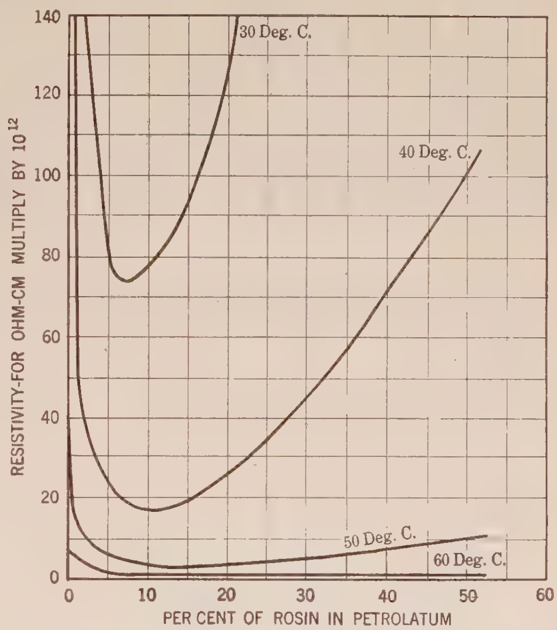

FIG. 17A—THE EFFECT OF ROSIN ON THE RESISTIVITY OF PETROLATUM

and Fig. 17B. At temperatures of 50 deg. cent. or less, the resistivity drops as rosin is added, up to 10 per cent, as shown in Fig. 17A. A further addition of rosin raises the resistivity again, but no amount of rosin added will bring the resistivity up to its original value. At higher temperatures, the addition of rosin up to 10 per cent lowers the resistivity. Further addition of rosin holds the resistivity approximately constant, as shown, for example, by the 80-deg. curve in Fig. 17B.

3. It should be noted that tests lasting a half hour bear a more or less definite relation to the standard five-min. test and are, therefore, unlikely to be of any more value. Artificial aging tests, on the other hand, are made under conditions designed to promote deterioration, and therefore reveal something not shown by the five-min. test.

This reduction of resistivity of petrolatum in itself, does not necessarily have a bad effect upon the quality of the cable, but, unfortunately, the reduction in resistivity is accompanied by an increase in dielectric loss or power factor at the higher temperatures. If

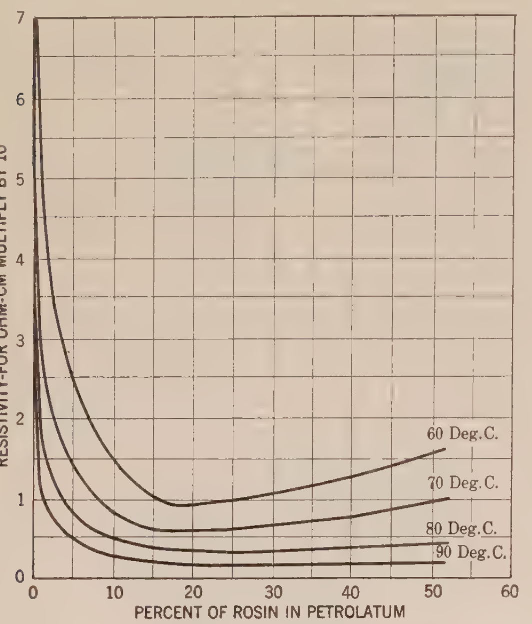

FIG. 17B—THE EFFECT OF ROSIN ON THE RESISTIVITY OF PETROLATUM

low power factor is obtained by the use of a large rosin content, such as 50 per cent, the compound becomes too stiff at low temperatures. In Fig. 18 are given two power-factor curves of two groups of cables.

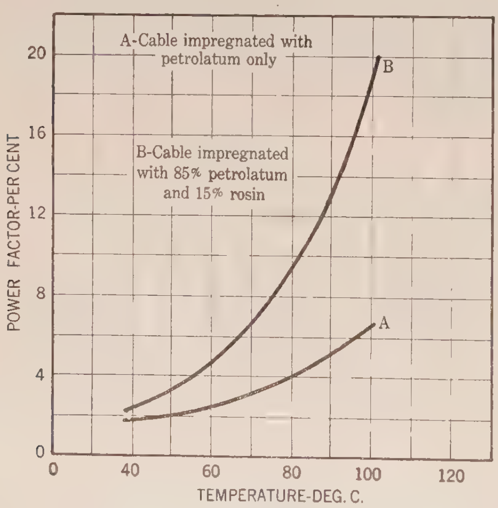

FIG. 18—RELATION BETWEEN POWER FACTOR AND TEMPERATURE OF A PAPER-INSULATED CABLE

These cables are identical, except the *B* cables contain 15 per cent of rosin, whereas the *A* cables contain no rosin. The serious effect of rosin in cables is that it lowers materially the critical temperature of cumulative heating.

The above data are presented to show that the use of rosin was stopped for definite and clearly understood reasons. This should not be construed as a final abandonment of this material, as further research work is under way which may lead to the development of methods of using it without incurring the disadvantages originally found.

Appendix II

HOT SPOTS IN CABLES

It has frequently been observed that impregnated paper-insulated cables, which have been subjected to a high dielectric stress for a considerable period, show hot spots which are regarded as incipient failures. It was recently the authors' good fortune to examine a piece of cable in which several hot spots occurred which showed practically all the characteristics which had been noted individually in previous cases.

The cable was single-conductor stranded, having a cross-sectional area of 600,000 cir. mils and insulated with 39/64ths of manila rope paper, applied with an open butt. The power factor of the insulation was about 1¾ per cent at 85 deg. cent.

This cable was subjected to 135,000 volts alternating for about twenty minutes and opened for examination.

There were 108 layers of paper, of which the outer ones were 8 mils and the inner ones 5 mils thick. The 8-mil paper was found to be entirely free from any evidence of puncture or hot spots. The same applies to the outer few layers of 5-mil paper, but upon reaching about the fiftieth paper from the conductor, evidences of hot spots became numerous.

The first evidence consisted of a tree-like design such as is characteristic of photographs of lightning and other high voltage discharges.[4] Upon examining these "tree" marks it was found that the paper fibers were charred. It was found that while the "tree" design in one layer nearly always crossed the "tree" design in the next layer, these designs were never superimposed, but each "tree" was independently formed, the general direction being across the tape. As more and more layers of paper were removed, the trunks of the "trees" were found to be more and more deeply charred until at about the 44th layer from the conductor, the paper was found to be burned right through. This continued for about fourteen layers when the charring gradually diminished until it ceased at the 18th layer from the conductor. The remaining papers down to the conductor were found to be merely punctured, each paper having a small hole with a charred edge. Other hot spots of a similar character were found which, however, did not extend to the conductor, but were confined exclusively to the intermediate layers of tape. An unpleasant odor was noticed in the vicinity of the tree patterns.

The existence of tree patterns proves the occurrence

4. F. A. S. Kleine, C. F. Proos, and J. C. van Stavern, Conference Internationale des Grands Réseaux Electriques, 1923, observed the same effect in European cable.

within cables of what is generally known as surface leakage.

Surface leakage occurs at all voltages, being merely conduction through films at low voltages, but partaking of the nature of streamers as the air ionizes at higher voltages. Hence, at low voltages, it obeys Ohm's law, but at high voltages, the volt-ampere characteristic depends upon ionic saturation.

The air ionization theory as generally understood, is that at a certain stress, the dielectric loss increases to such a high value that local cumulative heating occurs. Furthermore, according to this theory, a sudden increase of power factor with gradually increasing voltage, presages destructive ionization.

It is our opinion that this theory is not complete and requires a new interpretation; and we believe that the surface leakage phenomena described above, suggest the necessary modification.

Leakage current flows at low voltage without visible manifestation but at high voltages, ionization of the air causes it to flow as streamer discharges with a liberation of energy which varies with the degree of ionization. Failure results from charring of insulation either along the path or at the ends of the streamer.

While the surface leakage theory is based upon visual observations, it is of interest to note how it explains certain phenomena better than the orthodox ionization theory.

1. The lower specific capacity of air films should tend to divert the electrical stress to the surrounding insulation of higher specific capacity. The films, therefore, will not carry k times the ambient stress but considerably less. This would lead one to expect signs of failure around the edges of air films, but these are never found. All the signs of burning occur squarely on the surfaces exposed to the air films, as would be expected if caused by surface leakage.

2. Some cables in which there are numerous large air films in which ionization presumably occurs, have operated satisfactorily at high stresses for years without trouble. In such cases, the reason for the absence of streamers was probably low resistivity of the oil which kept the leakage in the stage of ohmic conduction, and thus restrained the local liberation of energy. Such cables, however, fail from cumulative heating when loaded.

3. It is a part of the film ionization theory that the increase of power factor with voltage is due to air ionization. If a cable be made without adequate drying of the paper and poorly impregnated, the increase of power factor with voltage should be quite marked, as the specific capacity of the solid part of the insulation will be abnormally high, thereby throwing a higher stress on the air films. Experiment shows, however, that in such a cable the power factor will be constant over a wide range of voltage. This is entirely consistent with the leakage theory, because, as suggested above, in a cable made of low resistivity, oil and paper, the leakage current will increase with the voltage according to Ohm's law over the full range.

AMERICA LEADS IN ELECTRIC BRASS MELTING

In the electric brass melting field, the United States has attained a tremendous lead over all foreign countries according to a report just made public by the Department of the Interior through the Bureau of Mines. Whereas in the United States there are about 540 active electric furnaces doing commercial non-ferrous melting, it is doubtful whether all foreign countries combined use 100 electric brass furnaces. Of the American furnaces, about 275 are induction furnaces, about 135 are moving indirect arc furnaces, 80 are Baily furnaces, while the remaining 50 furnaces are of various types.

The possibilities and limitations of the electric brass furnace are becoming better understood, the Bureau of Mines declares. The increase in the number of furnaces installed indicates that the growth is likely to continue, and that the electric furnace is of decided use to the non-ferrous metal industry. No radically new types of electric brass furnaces have been introduced in the United States in the last two years. The outstanding developments are the continued increase in the use of the induction and the rocking-arc types, and the lack of increase of less efficient types such as the granular-resistor and the muffled-arc types. The popularity of the two chief types has been attained because both are efficient, both give lower metal losses than fuel-fired furnaces, and both stir the metal so as to give perfect mixing.

The induction type is more or less standard for 24-hour operation in the rolling mill on yellow brass, and the rocking-arc type is more or less standard for red brass and for general foundry work. Unless the problem of a satisfactory lining for the induction furnace on red brass is solved, the field will probably continue to be divided in that fashion.

It is now generally accepted that no type nor size of furnace which cannot melt red brass at 325 kilowatt-hours per ton, or less, on 9-hour service under test conditions, or 375 kilowatt-hours per ton or less under the handicap of ordinary foundry delays, is efficient enough to compete successfully, with other types which will do this.

Serial 2597, "Present tendencies in electric brass-furnace practise," by H. W. Gillett, chief alloy chemist, and E. L. Mack, assistant alloy chemist, has just been issued by the Bureau of Mines. This report describes the trend of developments in electric brass-furnace practise in the last two years, and supplements Bureau of Mines Bulletin 202, "Electric brass-furnace practise," which was published in 1922. Serial 2597 may be obtained from the Department of the Interior, Bureau of Mines, Washington, D. C.

Theory of D-C. Excited Iron-Core Reactors and Regulators

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Review of the Subject.—*In the usual electrical machinery the magnetic saturation characteristic of iron is a handicap and in a-c. circuits gives rise to such undesirable characteristics as wave distortion and variable reactance, decreasing with increasing load. Furthermore, these characteristics are inherent in the material and can not be controlled by design to suit individual requirements or changing load conditions. Control of these characteristics can, however, be accomplished if the mean magnetic density in the core be controlled by means of a suitable d-c. excitation, in which event, the saturation characteristics of the iron can be put to some useful applications.*

(1) *APPLICATION AS A FREQUENCY MULTIPLIER*

The second and third harmonics of magnetization have been utilized in radio to multiply the supply frequency. Using a sufficient number of stages, theoretically any desired radio frequency may be obtained from commercial frequencies. However, the efficiency and regulation of the scheme are very poor, and this application has therefore become almost obsolete by the advent of the vacuum tube oscillator and the high-frequency alternator. When used at all, the number of stages would be kept to a minimum.

(2) *APPLICATION AS A SERIES CURRENT-LIMITING REACTOR*

The ordinary iron-core reactor is saturated at increasing values of load, and thus having a much lower reactance at short circuit then at normal load, is undesirable as a current-limiting reactor. However, its characteristic is inverted over a wide and useful portion of the curve when excited by means of direct current, so that it shows an increasing reactance with increasing load. By suitable design, the maximum reactance may be made to coincide with the short-circuit condition without departing from the usual economical values of flux and current densities and from the economical ratios of core and copper. The ratio of the short-circuit reactance to normal-load reactance may be as high as three to one. This characteristic of the d-c. exciter reactor does not mean that the d-c. excitation increases the permeability of the core and the reactance of the winding, but just this, that the fixed d-c. excitation lowers the effective permeability and reactance at normal loads many times more than at short-circuit, and thus the short-circuit reactance becomes much higher than the normal reactance. This highly desirable rising-reactance characteristic of the d-c. excited reactor is at the expense of higher losses and cost, and therefore, unless there is a very particular need for the rising-reactance characteristic, the use of this type of a reactor is not recommended.

(3) *APPLICATION AS A FEEDER VOLTAGE REGULATOR*

A pair of auto transformers of suitable design (equipped with suitable windings for d-c. excitation) may be utilized as feeder-voltage regulators. A number of such sets have been built and tested and some have been put into service. This type of a voltage regulator has a number of advantages over the other types in that, (a) it has no moving parts, (b) can be designed for any voltage on account of its transformer construction, (c) is four or five times or more as fast in operation as some other types and, (d) can be built mechanically much stronger to withstand short-circuit forces. Its disadvantages are high losses and higher cost in all instances where the induction regulator can be designed for the line voltage without transformers. This type of a voltage regulator is therefore desirable only when high speed of operation is essential or when the circuit voltage is very high.

(4) *APPLICATION AS A SHUNT REACTOR FOR POWER-FACTOR CONTROL*

A d-c. excited reactor may be used also as a shunt reactor constituting a variable reactive load on the lines to control power-factor by varying the d-c. excitation. A possible application is to the neutralization of charging current of high voltage transmission lines and control of line regulation. In this application the wave-shape of the reactor current becomes of importance. Many oscillograms taken in various three-phase connections are given, which seem to indicate that although very pure sine wave of current can not be obtained economically, yet the harmonics may be reduced to practically harmless proportions.

RATIO OF CONTROLLING AND CONTROLLED KV-A.

The control of the output of a reactor may be by alternating current as well as by direct current, the frequency of the controlling current being independent of the frequency of the controlled current. To a first approximation, and ignoring the copper losses, the ratio of the kv-a. of the controlling current to the kv-a. of the controlled current is that of the ratio of the respective freqencies. This principle has been taken advantage of in Alexanderson's "Magnetic Amplifier" in the modulator circuit of his system of radio transmission. In d-c. control, the necessary control kv-a. is just the copper loss approximately corresponding to the controlled kv-a.

Introduction

THE superposition of d-c. excitation on an iron-core static alternating current apparatus, such as a reactor, or transformer or autotransformer, modifies its characteristics very profoundly and leads to new problems and a variety of applications. Some of the more important applications are[1]

1. Frequency converter, or high-frequency generator, suitable for use in radio.

2. Short-circuit current-limiting reactor having inherently low normal reactance and inherently high short-circuit reactance.

3. Feeder voltage regulator with no moving parts, for central station and laboratory use.

4. Variable series reactor with no moving parts, with d-c. control of its reactance to regulate load current or voltage.

5. Variable shunt-reactor with no moving parts, with d-c. control of its a-c. exciting current, constituting an adjustable reactive load, for use, for instance, for the neutralization of the charging current of high-voltage transmission lines and also thereby for the control of their regulation.

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1. See also the companion paper by Mr. D. K. Blake, on "Applications of Saturated Core Reactors and Regulators."

Abridgment of paper presented at the Annual Convention of the A. I. E. E., Edgewater Beach, Chicago, Ill., June 23-27, 1924. Copies of the complete paper may be obtained on application.

General Theory

Three characteristics of iron-core reactors (without d-c.) are commonly known: *viz.*

(a) The reactance of an iron-core reactor depends on the core-density on account of the variable permeability of iron.

(b) Due to this same cause, the current taken by such a reactor at sine wave voltage (or the voltage consumed at sine wave current) is distorted; and

(c) Such a reactor is entirely unsuited for short-circuit protection because, due to saturation, its short-circuit reactance is much lower than its normal reactance, while the requirements of a desirable protective reactor are that if possible it should have a low reactance at normal loads and a high reactance at short-circuit.

From the first characteristic mentioned above, it follows that if the mean density of the core be controlled by the superposition of a d-c. excitation, the reactance of the apparatus can be controlled thereby. This is the basis of the applications 3, 4 and 5 mentioned above.

From the second characteristic mentioned above, it follows that by biasing the core density by means of d-c-excitation, more wave distortion may result. This feature is taken advantage of in the application for the generation of high frequency for radio. This application, however, has been rendered obsolete by the advent of the vacuum-tube oscillator and will, therefore, not be discussed in this paper. In other applications, wave distortion and harmonics are objectionable and must be eliminated or minimized. While at first sight it might appear that wave distortion will be so bad that no applications other than the production of harmonics could be practicable, yet experience shows the reverse to be true, so that while wave distortion can be minimized so as not to be a limitation to most applications, it can not be accentuated and loaded for the production of harmonics to as great as degree as one would expect[2].

The characteristics that have been indicated so far do not as yet give any clue as to the suitability of a d-c. a-c. excited reactor for short-circuit protection. This application results from the fact that the d-c. excitation accentuates very markedly the lower bend of the magnetization curve of iron, as will be discussed in detail under the heading of "Volt-ampere Characteristics of DC-AC. Excited Core."

Schemes for the Application of D-C. Excitation

In applying d-c. excitation to an a-c. apparatus, provision must be made for protection against three possible disturbances, *viz.*

1. The d-c. supply circuit must be protected from induced alternating voltages, and, if possible, also from alternating currents.

2. For all applications, except for the generation of high frequency for radio, the line currents and voltages should be symmetrical and of as good shape as possible.

Both of these conditions can be satisfied by using two subunits balanced against each other as shown in Figs. 1, 2, 3 and 4 instead of using a single-core single-unit. In these figures the arrows show relative directions of a-c. and d-c. fluxes, a consideration of which will show that normally no a-c. voltage will appear between the d-c. terminals. For instance, considering Fig. 1, it will be evident that the a-c. voltages induced in the d-c. coils D_1 and D_2 will neutralize each other, and no a-c. voltage of normal frequency will appear between the d-c. line terminals. However, in this case there will be an a-c. voltage to ground from these terminals, and this high potential stress will be impressed on the d-c. supply system. Usually the d-c. winding has many times the

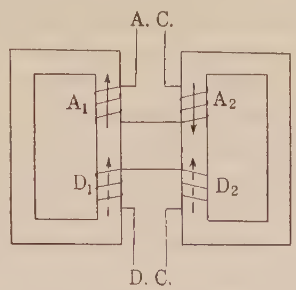

Fig. 1—Connection of Two Single-Phase Transformers as a Reactor Suitable for D-C Excitation. Solid Arrows Represent A-C. Flux, Dotted Arrows, D-C. Flux

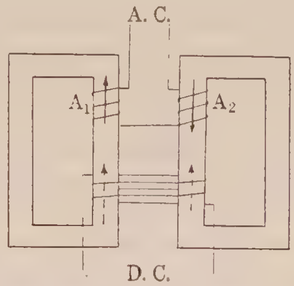

Fig. 2—An Improvement over the Arrangement Shown in Fig. 1. The D-C. Coil Surrounds both Units at Once, and Therefore no A-C. Voltage of Fundamental Frequency can Build up in it. Solid Arrows Represent A-C. Flux, Dotted Arrows D-C. Flux

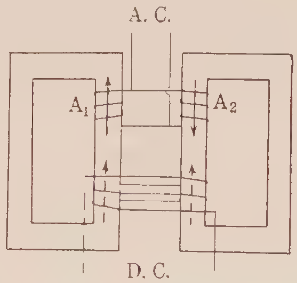

Fig. 3—An Improvement over the Arrangements Shown in Figs. 1 and 2. A Second Harmonic Current Circulates in the Parallel Branches of the A-C. Circuit, and no Appreciable Second Harmonic Voltage Appears Anywhere

2. See the complete paper for the discussion of wave-shape illustrated with many oscillograms.

turns of the a-c. windings, and this voltage would amount to a great deal. This disadvantage may be practically oviated by grounding the d-c. supply system of one of the terminals, but, even then, the d-c. winding will require insulation corresponding to its maximum induced voltage. The difficulty is completely obviated by making the d-c. winding to enclose the two cores at once as shown in Fig. 2. Here the induced voltage is neutralized in each turn and therefore no large a-c. voltage can appear in any part of the d-c. circuit, regardless of the number of turns of the d-c. coil.

Although the normal frequency voltages induced in the d-c. winding neutralize each other in every turn in the design of Fig. 2, yet, whenever there is wave distortion (and there always is some wave distortion) the even harmonics of the induced voltages do not cancel each other in each turn of the d-c. coil but add to each other, and if the impedance of the d-c. supply circuit is high enough not to short-circuit this voltage (as for instance in the case in which the current of the d-c. coil represents full load to the d-c. generator), destructive even harmonic voltages may appear across the d-c. circuit. This difficulty is practically completely eliminated by connecting the two a-c. coils A_1 and A_2 in parallel as shown in Figs. 3 and 4, instead of in series as in Fig. 2. The even harmonics are then short-circuited and circulated in the a-c. coils without appearing anywhere in the outside circuits. This is a desirable feature, not only on account of the elimination of avoidable voltage stresses, but also on account of the additional advantages that by this means, (a), the wave shapes of currents and voltages in the external lines are improved, (b), the effectiveness of the d-c. excitation in controlling the a-c. reactance is increased, and (c), the time constant of the apparatus is reduced and its speed of response to changes in the controlling d-c. excitation is increased.

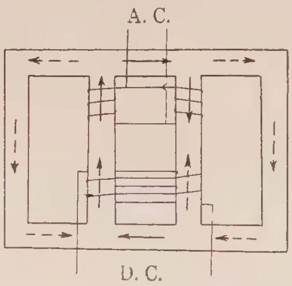

Fig. 4—Showing the Core Construction which is Preferred as Eliminating the Straying of A-C. Flux and Reducing Losses

Volt-Ampere Characteristics

The volt-ampere characteristics of a device like that of Fig. 3 is shown in Fig. 5. A number of characteristics may be observed as follows:

1. By applying sufficient d-c. excitation, the a-c. current taken by the device at a given voltage (or the voltage consumed at a given current) may be controlled over a very wide range. The lowest limit to this voltage consumed, or the highest limit to the current taken, is fixed by the impedance which the device would have without the iron core. That is, at increasing relative values of d-c. excitation, the volt-ampere characteristics of the device is as though it had no iron core.

2. There is an economic limit to the value of d-c. excitation and range of control, because beyond a certain zone the addition of more d-c. excitation does not produce a proportionate change in the a-c. current or voltage. For instance, at 100 amperes a-c., the application of 100 amperes d-c. cuts down the voltage from 118 to 29. If the d-c. excitation be doubled, the voltage is reduced to 12; if it be doubled again, the voltage is reduced to about 7.

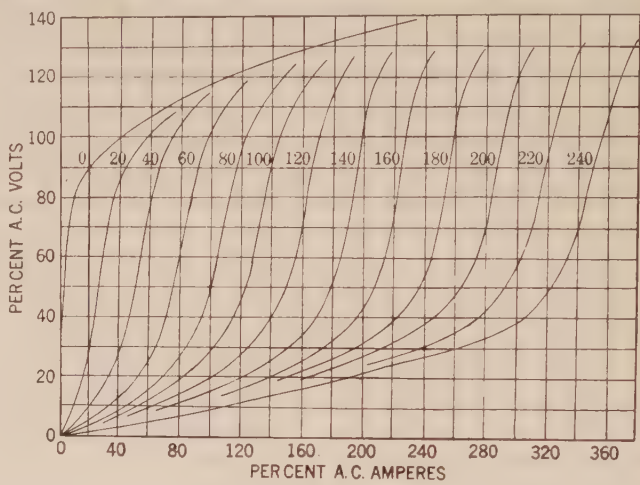

Fig. 5—Volt-Ampere Characteristic Curves of a Core with Simultaneous D-C. and A-C. Excitation. Numbers of the Curves Refer to the D-C. Amperes. Turn Ratio of D-C. and A-C. Windings 1:1. Tests Made with Approximately Sine-Wave Voltage

3. The volt-ampere curve for combined d-c-a-c. excitation has two bends—one at the lower densities, the other at the higher densities. The volt-ampere curve for pure a-c. has also two such bends, but just because the lower bend occurs at extremely low core densities and small values of current, it does not show in the usual curves drawn for the working range of currents and voltages. If the initial portion of the a-c. volt-ampere curve for zero d-c. is drawn to a large scale, it looks as shown in Fig. 7, exposing the lower bend. In the light of these remarks, and by again referring to Figs. 5 and 6, it will be evident that the addition of d-c. excitation does not introduce a new bend to the curve but shifts the two bends of the a-c. volt-ampere curve far towards the higher values of current and voltage, and this fact makes it possible to make commercial use of the lower bend as in an automatic protective reactor having low inherent normal reactance and high inherent short-circuit reactance.

That the volt-ampere curve with superposed d-c. must have two bends or knees may also be seen with the aid of the following theoretical considerations.

Since the d-c. excitation is kept constant (though of different value for different curves) and only the a-c. current and voltage are varied in these volt-ampere curves, it will be evident that at the initial parts of the curves (near the origin) the d-c. current will be many times the a-c. current, and the reactance of the unit will be completely determined by the d-c. density in the core. The initial part of the volt-ampere curve is therefore straight and has a slope very much smaller than that of the zero-d-c. volt ampere curve. That is, the reactance or voltage drop at this point of the curve is very low as compared with the zero-d-c. curve. This fixes the general character of the initial end of the volt-ampere curve.

Considering the final end of the volt-ampere curve, it will be evident that as we go higher and higher in the a-c. flux density and current, the fixed d-c. excitation will be a smaller and smaller percentage of the total current and will therefore less and less influence the a-c. volt-ampere characteristic. That is, the final end of the volt-ampere curve with d-c. excitation will approach asymptotically the volt-ampere curve without direct-current.

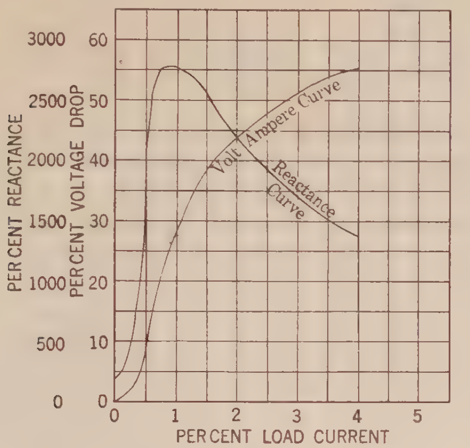

FIG. 7—THESE CURVES SHOW THAT ON A CERTAIN COMMERCIAL SIZE OF AN ECONOMICAL TRANSFORMER OR REACTOR DESIGN, THE USEFUL RANGE OF THE CORE REACTANCE CORRESPONDS TO A CURRENT WHICH IS LESS THAN 1 PER CENT OF THE RATED CAPACITY OF THE WINDING

Having thus determined the character of the initial and final parts of the curve, it will be evident that the smoothest or simplest curve that will join these two parts will require two bends or knees.

The place where the mean value of the a-c. current equals the value of the d-c. current would be approximately the inflexion point of the curve, that is, below this point the d-c. will be dominant and the curve will be convex downward; above this point the a-c. will be dominant and the curve will be convex upward.

Examining Fig. 5, it is found that this is approximately true. Assuming sine wave a-c., the inflexion point corresponds to an a-c. of which the mean value is only ten to fifteen per cent higher than the d-c. This is a good qualitative check, as the analysis given above is not intended to be anything but qualitative on account of the varying permeability of the core along the cycle.[3]

THEORY OF THE APPLICATION OF THE D-C-A-C. EXCITED REACTOR AS A PROTECTIVE IMPEDANCE

The most desirable characteristic of a protective reactor is that it should have a low inherent reactance for the normal load current and a high inherent reactance for short-circuit. An iron-core reactor (without air gap), that can be commercially or economically designed, fails to meet this condition, because increasing currents saturate the core and reduce the reactance. This statement has to be qualified as applying to "commercial or economical" designs, because if the core be operated normally at densities below the lower bend, the desired characteristics may be secured, although at a very prohibitive cost.

The a-c. volt-ampere curve (with zero d-c.) of Fig. 5 is plotted to a large scale in Fig. 7. In order that the economic significance of the currents and voltages may be easily grasped, the currents are given in per cent of what would correspond to the normal current of a commercially economical transformer of the same proportions as the reactor under consideration and the voltages are given in per cent of the normal rated voltage of the equivalent transformer. The normal density or voltage and the normal current are, of course, somewhat arbitrarily fixed, but inasmuch as these curves are to be used for comparative purposes and not for their absolute values, a very great deal is gained in intelligibility by specifying per cent voltage and per cent current representative of economical practise even though somewhat arbitrary. From the volt-ampere curve, a reactance curve has also been calculated and plotted against the per cent current.

Referring to the reactance curve of Fig. 7, the following characteristics will be observed:

The maximum reactance of the unit, which is desired to occur at short circuit, occurs at about 1 per cent of its normal rated current. To be used as a protective reactor, then, the unit must be operated normally at a small fraction of one per cent capacity so that the short circuit will be about 1 per cent load to it. This is indicative of the degree of its economic merit. The larger the capacity of the unit, the smaller will be the per cent load at which its maximum reactance occurs if no d-c. excitation is used.

The addition of direct current, however, shifts the two bends of the volt-ampere curve and the maximum of the reactance curve towards higher values of current and voltage. By using sufficient d-c. excitation, the

3. For a discussion of the differences of the volt-ampere characteristics for sine-wave voltage and sine-wave current, see the complete paper.

useful range of the reactance curve may be brought to any desired value of current or voltage or kv-a. In the unit on which the curves of Fig. 5 were taken, 200 amperes might represent full-load current, and we find that 240 amperes d-c. curve makes the unit a most desirable protective reactor. This curve is plotted in Fig. 9 in terms of per cent load current, per cent voltage drop and per cent reactance. We find that at normal load current the device consumes about 15 per cent voltage, that is, it has 15 per cent reactance; while at short circuit it has 50 per cent reactance, making the short-circuit current only twice normal. While practically in all the other apparatus, the short-circuit reactance is either the same as, or smaller than, the normal reactance, in a properly designed d-c-a-c. reactor, the short-circuit reactance may thus be about three times the normal reactance.

The value of d-c. excitation that brings the useful

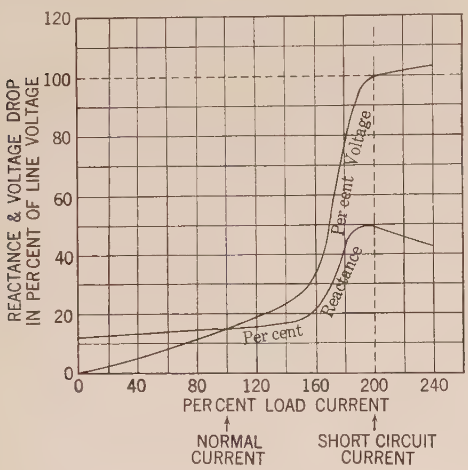

Fig. 9—Volt-Ampere and Reactance Curves of a Reactor With Superposed D-C. Excitation

Note how the reactance increases with increasing load, being about 12 per cent at no-load, 15 per cent at full-load, and about 50 per cent at short-circuit. The curves are only illustrative; the practical range of variation of reactance is somewhat less than this

range of the reactance curve to the normal working load of the unit is of the order of 120 per cent—160 per cent of the a-c. excitation (effective values). This holds true for apparatus sizes. Theoretically, in "peanut" sizes the d-c. excitation might be dispensed with, since the smaller the unit, the lower the economical core density would be and the nearer its magnetizing current would approach the value of its rated load current.

In a protective reactor of this type, it is not necessary to remove the d-c. excitation on short-circuit. Referring to Fig. 5, it will be seen that above the upper bends of the volt-ampere curves, there is very little difference in the voltage consumed with or without d-c. excitation. This is due to the fact that at this point the d-c. ampere turns, being much smaller than the a-c. ampere turns, have very little effect on reactance.

The d-c. to a-c. excitation ratio must not be misinterpreted as though it were a power ratio, for it is merely an ampere-turn ratio within the reactor, while the ratio of d-c. power to a-c. power or volt-amperes is only of the order of one or two per cent, that is, the d-c. power that is necessary to operate such a device is that required to furnished the copper loss and is therefore only a couple of a per cent of the a-c. volt-ampere or less, depending the kv-a. rating of the unit.

The consideration of the ratio of the power of controlling current (in this case d-c.) to the controlled current (a-c.) has an interesting bearing to the cases where both the controlling and controlled currents may be alternating. Ignoring the resistance losses, we could say, as a general rule, that the ratio of the volt-amperes in the controlling and controlled currents is the same as the ratio of their frequencies. This principle has been utilized by Mr. Alexanderson in radio in what has been called a "magnetic amplifier" being a reactor of this type in which the controlling current is of telegraph key or audio frequency while the controlled current is of radio frequency.

Advantages and Limitations of the Series Protective Reactor

The main advantages of this type of a current-limiting reactor are: (1) as already explained, it has a much higher reactance at short-circuit than at normal load; and, (2) its reactance is entirely inherent and automatic without requiring any relays, switches or other control equipment.

The main limitations of such a reactor are its cost and losses. (1) The cost of such a reactor may be estimated as follows: the reactor must be good for the normal load current and the line voltage, hence it will have a kv-a. rating of the same order as the load kv-a. Since the reactor has two windings, one for a-c. and one for d-c., it is equivalent to a transformer of the same kv-a. rating as the load. The d-c. ampere-turns are from 20 per cent to 60 per cent greater than the a-c. ampere-turns, but this is partially offset by the fact that the core density for the short-circuit condition may be designed for a much higher value than that of a normal transformer. That the complete reactor has to consist of two subunits tends to increase its cost somewhat above its equivalent transformer kv-a. rating would indicate. In concrete terms, then, such a reactor for a 1000-kv-a. circuit will have a cost somewhat greater than that of a 1000-kv-a. transformer. This fact naturally limits its very extensive application. If it should be desired to maintain the short-circuit current indefinitely on the ground that it is only two or three times normal current, the rating and cost of the reactor is naturally further increased.

(2) The losses of such a reactor are of the same order of magnitude as those of the equivalent transformer.

A further limitation of the series reactor that might be mentioned is, if the short-circuit starts with a large transient flux component, the protective or current-limiting ability of the reactor is temporarily paralyzed,

and the current is limited largely by the air-core reactance of the windings, until the transient has practically died out. This transient characteristic is well shown in Fig. 14. Note the initial rush of current at sudden short-circuit. This oscillogram was taken on a connection similar to Fig. 1 and therefore shows a prominent normal second harmonic plus a transient fundamental in the d-c. circuit. This second harmonic would be almost entirely absent in the d-c. circuit if there were a multiple connection in the a-c. circuit as shown in Figs. 3 or 4.

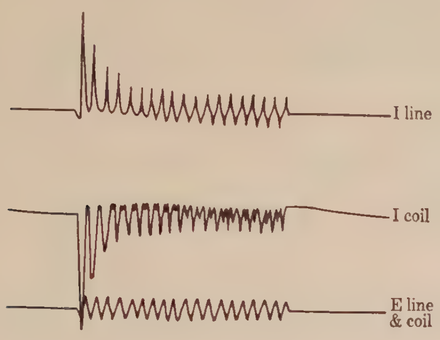

FIG. 14—TRANSIENT RUSH OF CURRENT DUE TO SUDDEN SWITCHING OF A D-C. EXCITED REACTOR

FEEDER VOLTAGE REGULATOR APPLICATION

Out of a number of ways in which the d-c-a-c. principle can be applied to voltage regulation, the one that has been found to give the best results is as follows: Suppose it is desirable to regulate the voltage 10 per cent above and 10 per cent below the normal voltage. Two autotransformers with 10 per cent secondaries and each equipped with a d-c. winding are connected into the circuit as shown in Fig. 15, that is, the primaries of the two autotransformers are connected in series with each other and across the supply lines, and the secondaries are connected in series with each other and in series with the load or feeder lines. One of the secondaries is reversed, so that one unit tends to raise the feeder voltage, the other tends to lower it. Each autotransformer unit consists of two subunits and has therefore two primary windings and two secondary windings, and one d-c. winding enclosing both subunits as shown in Figs. 2 to 4. If one pair of a-c. windings, as for instance the two secondaries of one unit, is connected in parallel, the other pair, that is, the two primaries of the same unit, may be connected in series if desired.

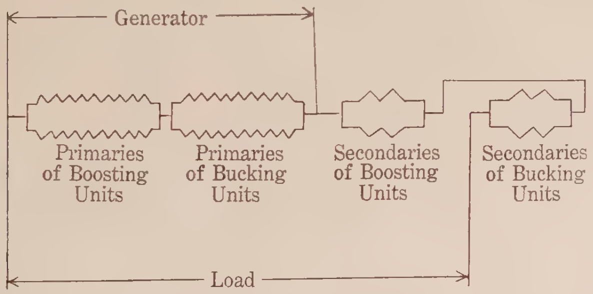

FIG. 15—CONNECTION OF TWO AUTO-TRANSFORMERS AS A VOLTAGE REGULATOR, ONE TENDING TO BOOST THE LINE VOLTAGE, THE OTHER TENDING TO LOWER IT. THEIR RELATIVE VALUE AND RESULTANT EFFECT IS CONTROLLED BY VARYING THEIR D-C. EXCITATION

The operation of such an equipment is as follows:

(*a*) *No-load operation.*

Referring to Fig. 15 it is seen that unit No. 1 tends to raise the load voltage and unit No. 2 tends to lower it. As the two units may be assumed duplicates, therefore normally with equal or no d-c. excitation in either unit, they balance each other and the load voltage is neither raised nor lowered. Suppose the d-c. coil of No. 2 is fully excited, and that of No. 1 is unexcited. Then, unit No. 2 will be saturated and will have a negligible reactance and No. 1 will take up the full-line voltage, and thus the line voltage instead of dividing equally between P_1 and P_2, will be concentrated practically entirely across P_1. If the voltage across P_2 is negligible, that induced in S_2 will also be negligible, and the voltage across S_1 will be practically 10 per cent of the line voltage and will boost the feeder voltage by this percentage. This gives us the maximum boosting condition.

If now the d-c. winding of No. 1, the "boosting" unit, is fully excited, and that of No. 2, the "bucking" unit, is left unexcited, the "boosting" unit will be saturated and will therefore have negligible reactance and negligible voltage drops across its primary and secondary, while the "bucking" unit takes up the full line voltage and its secondary "bucks" the load voltage by 10 per cent. This gives us the maximum "bucking" condition.

Intermediate values of load voltage between maximum "boost" and maximum "buck" are obtained by intermediate values of d-c. excitation in the two units.

(*b*) *Full load operation.*

Under load conditions the general operation of the device is exactly as described for the no-load condition, except that the amount of regulation is somewhat modified by the reactive drop through the device. The power transformation through the device being proportional to the secondary voltage, the magnitude of the primary current is also proportional thereto.

It follows, therefore, that at maximum and minimum load voltages, one unit acts as a transformer, the other as a reactor. At intermediate values of voltages, the units act partially as transformers and partially as reactors.

A number of such regulators has been built and tested in sizes from a few kv-a. up to 460-kv-a. feeders. Some of these have been put into service and are giving perfect satisfaction. A large regulator for 460-kv-a. output is shown in Figs. 20 and 21, in elevation and plan, respectively.

Automatic Control of D-C. Excitation

Since a commercial voltage regulator must be automatic, it is necessary that the control of d-c. excitation be automatic and be governed from a contact-making voltmeter. A number of schemes has been developed to accomplish this.[4]

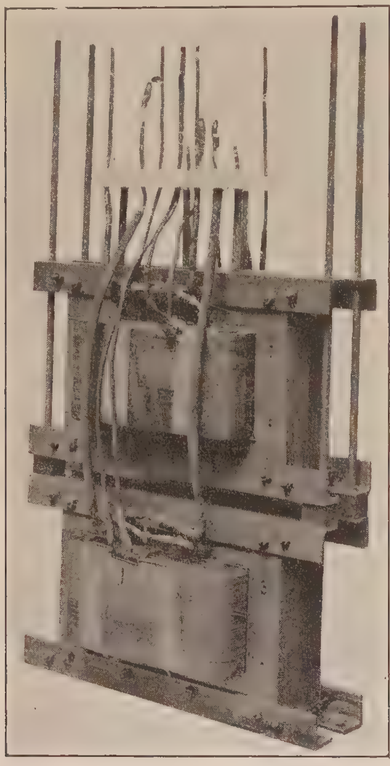

Fig. 20—Core and Coils of a 46-Kv-a. Regulator (460-Kv-a. Output) for 60-Cycle, 2300-Volt Circuits

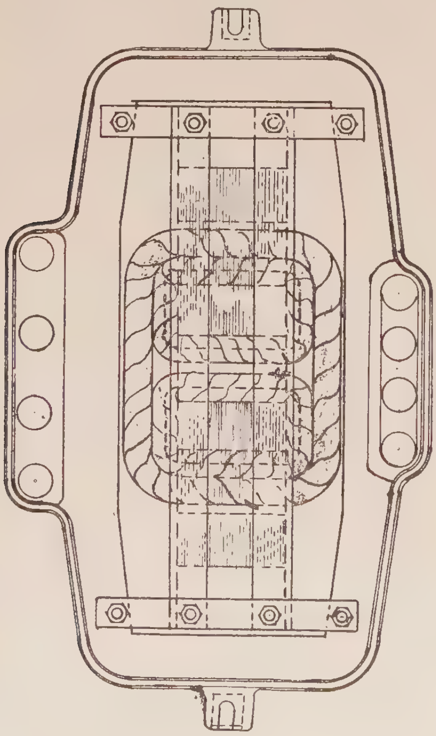

Fig. 21

Wave-Shape

A large number of oscillograms was taken on some of these regulators, and those which are representative of various conditions of operation are here reproduced.

Advantages and Limitations of this Type of Regulator

A. The main advantages are:

1. *Speed of Operation.* While the average induction regulator requires 8 to 12 seconds to go from maximum "boost" to maximum "buck," this type of a voltage regulator requires only between one and two seconds for a similar change. The time required is the combination of the time constants of the regulator, d-c. generator, and control equipment.

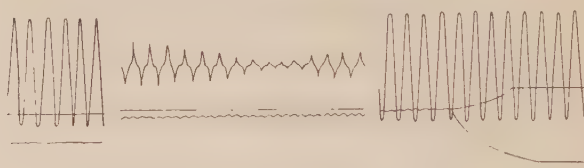

Fig. 33—Switching Test at No-Load, Changing from Maximum Boost to Maximum Buck. Film Cut and Shortened at Two Points. Top Wave: Total Secondary Series Voltage

Note how it decreases to zero and then builds up in reversed phase, so as to change from "boost" to "buck." Middle and bottom waves: the D-C. currents in the two units one building up, the other dying down

2. *Suitability for High Voltages.* Since the construction of this regulator is that of a transformer, it can be designed for any voltage desired, while induction type regulators may be said to have an upper limit of 13,000 volts. For circuits above that voltage, an induction regulator requires two transformers, one for its primary, and one for its secondary.

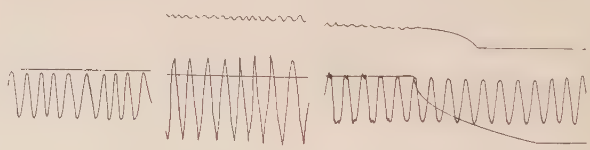

Fig. 34—Switching Test at Full-Load, Changing from Maximum Boost to Maximum Buck. Bottom Wave: Total Secondary Series Voltage

Note that it does not diminish but actually increases during the transition period, the change from *boost* to *buck* being accomplished by a gradual reversal in the phase of the total secondary (series) voltage

3. *Greater Mechanical Strength.* Since this type of a regulator has no moving parts, it can be built much stronger than movable or rotatable regulators to withstand the short-circuit stresses which are very severe in all regulators on account of their autotransformer connection. The ability of this static regulator to withstand short circuits is further improved by its

4. See complete paper.

higher inherent reactance. This advantage probably is not as great as one might expect on account of the fact that on short circuit all autotransformers are severely overexcited and hence the saturation of the cores must be reckoned with.

B. The limitations of this type of a regulator are:

1. Higher cost for low voltages. At 6600 volts or lower, this type of a regulator costs somewhat more than an induction regulator of the same capacity. This is due to the fact that the equivalent transformer rating of such a regulator is about four times the maximum kv-a. which it transforms. Thus, first, the fact that a "boosting" and a "bucking" unit must be provided, doubles the size of the apparatus. Second, the fact that d-c. ampere-turns of sufficient capacity to neutralize the total primary and secondary a-c. ampere-turns must be provided for each unit, at least doubles the size of the apparatus again, and thus we have a regulator of which the equivalent transformer capacity is about four times the maximum kv-a. which it transforms.

However, at those high voltages for which an induction regulator would need insulating transformers, this type of regulator may prove more economical.

2. Higher Losses. Both on account of the duplication and multiplicity of windings, which tends to increase the copper losses, and on account of the superposed d-c-a-c. excitation of the core, which tends to increase the core loss, this type of regulator has higher losses than an equivalent induction regulator.

On account of these limitations, this regulator is as yet considered in a developmental stage and is not available for general commercial use.

Shunt Reactor Application

The shunt reactor application of such a device for the neutralization of the charging current of transmission lines has been considered in a number of instances by operating and consulting engineers, but no actual application has as yet been carried out. In such service, not only would such a device reduce the charging current load on the central station, but also would control the voltage of the line. In this latter service it would take the place of an underexcited synchronous condenser, and would have a number of advantages over it, namely, (a) a static device with no rotating parts and requiring practically no attention, (b) can be designed for any voltage, and, (c) would be more economical and more efficient than a synchronous condenser outfit requiring transformers. It, however, would have three disadvantages over the synchronous condenser outfit, in that, (a) while the voltage-regulating character of the synchronous condenser is inherent and very marked, so that it could perform to quite an extent without a contact making voltmeter control on its field, the performance of the static device has to be dependent on such a control and is therefore somewhat slower. In order that the losses of this device may not be excessive, it has to be operated not much above the upper bend of the magnetization curve and hence advantage can not be taken very economically of the flat saturation portion of the volt-ampere curve which corresponds to high losses and also to greater distortion. (b) While a synchronous condenser can operate either leading or lagging, this device can operate only lagging. (The range of lagging load, minimum to maximum, could easily be made 1 to 10 or 20). (c) The static device is bound to have a certain amount of wave distortion. The harmonics, however, would be in the current not appreciably in the voltage, and would, therefore, probably not do any appreciable harm except as a small useless reactive kv-a. to be furnished from the generating system. What wave-shapes of current are to be

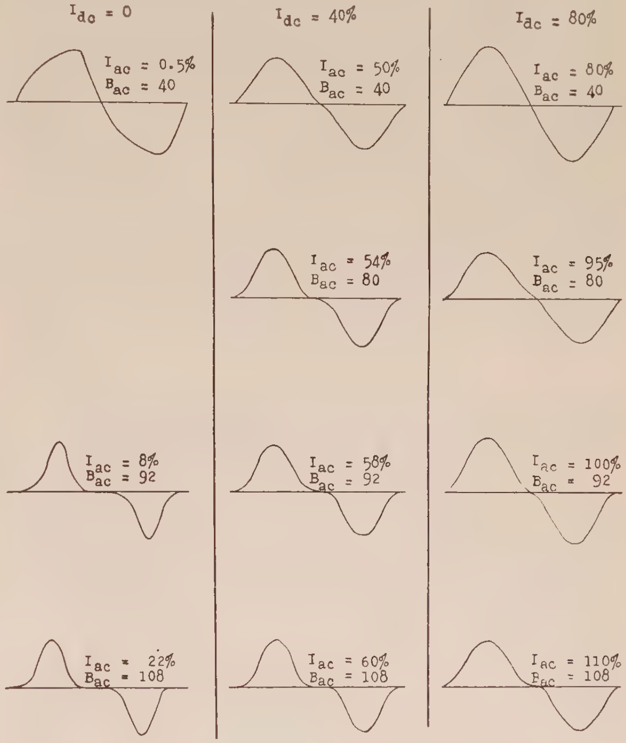

Fig. 46—Oscillograms Showing the Effect of A-C. Density, and of the Ratio of D-C. to A-C. Excitation on Wave-Shape of a Shunt Reactor

expected may be estimated from the following oscillograms.[5] Any such application must, necessarily, be polyphase, and although there are many possible polyphase connections, only a few have reasonably good wave form and all-around desirability.

It is interesting to note that polyphase applications are capable of yielding much better wave-shape than single-phase applications, on account of the fact that the triple harmonic, the most prominent harmonic, can be eliminated from the lines and circulated internally in three-phase connections but not in single-phase connections.

5. See the complete paper for oscillograms.

Wave Shape of Shunt Reactor

To get an exact idea of the wave shape which would be obtained on power size apparatus, some single-phase tests were made on a reactor of suitable design loaded to as high as 500 kv-a. The oscillograms taken under various conditions are grouped in Fig. 46 in three columns. The first column shows the exciting current wave-shapes at various core densities with no d-c. excitation. The second column shows wave-shapes at various densities with 50 per cent rated d-c. excitation, and the third column shows wave-shapes with 100 per cent rated d-c. excitation. It is evident that the larger the d-c. excitation and a-c. current, the purer is the wave-shape. The current wave at 80 kiloline density in the third column is so good that it seems to leave little to be desired. Judging from these oscillograms, it appears as though the additional a-c. current which is drawn on account of the presence of the d-c. current is very much purer in wave shape than the exciting current without d-c., and that therefore the numerical value of the harmonics at moderate densities are more or less constant or increase very little with increasing a-c. current drawn. Thus, with increasing a-c. current drawn, the percentage of the harmonics rapidly diminishes and the wave shape improves.[6]

6. For a discussion of the merits and wave-shapes of various three-phase connections and their oscillograms, see the complete paper.

Acknowledgment

The author acknowledges the co-operation of Messrs. W. B. Kirke, F. Dubsky and C. H. Kline in these investigations. The development of the automatic control for the regulator is due to Messrs. E. J. Murphy and L. W. Thompson.[7]

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7. For a brief historical review of the development of research on this subject, see the complete paper.

Technical Committee Annual Reports 1923-1924

Continued from page 857

ELECTROCHEMISTRY AND ELECTRO-METALLURGY COMMITTEE

To the Board of Directors:

This committee has during the past year continued the activity which was begun the previous year. As in 1923, it also in 1924 initiated a technical session held at the Spring Convention, devoted to electrochemical and electrometallurgical subjects. At this session, very excellent papers were presented which tended to indicate advances in the art and the status of the art in the respective fields covered. These papers were as follows:

(1) Maximum Demand Regulator for Electric Furnaces, by E. T. Moore.

(2) Manufacture of Phosphoric Acid in Electric Furnaces, by Theodore Swann and F. V. Andrea.

(3) Effect of Impurities on Battery Electrolyte, by G. W. Vinal and F. W. Altrup.

No regular committee meetings were held as all necessary business could be quite successfully conducted through correspondence. Four or five of the seven members of the committee have shown an active interest in the work. These were all unanimous in the belief that it would be a disastrous mistake to change the function and field of activity of this committee as proposed by the tentative report of the committee to review technical activities of the Institute, dated January 22, 1924. This committee also feels that the tentative report referred to proposes an improperly narrow and restricted basis for the whole activities of the Institute and much prefers to support the higher conception of the Institute and its technical committees, as outlined in the general remarks on Technical Committee Activities which were approved and passed at a meeting of the Meetings and Papers Committee on May 2, 1924.

It is proposed to continue the activity of this committee during the next year by obtaining papers relating to the engineering requirements and operation of electrical equipment in electrochemical and electrometallurgical processes and to initiate a technical session at which such papers may be presented and discussed.

This committee especially provides the technical liason between the A. I. E. E. and the American Institute of Mining & Metallurgical Engineers and the American Electrochemical Society, so far as electrochemical and electrometallurgical applications are

concerned. It is therefore the province of this committee to report that the two engineering societies mentioned have given considerable attention during the past year, and have, in fact, conducted several technical sessions at which a number of excellent engineering papers have been presented on subjects in which many electrical engineers, and accordingly the Institute, should be interested. As a matter of record, and for the sake of reference, a list of these papers is being included in this report. At the Mid-Winter Convention of the American Institute of Mining and Metallurgical Engineers held in New York on February 18th to 21st, 1924, the following papers of mutual interest to electrical and metallurgical engineers were presented:

(1) Direct Electrolysis of Black Copper Anodes of High Nickel-Lead Content, by M. H. Merriss.

(2) Electric Welding of Large Storage Tanks, by Harold C. Price.

(3) Greenwalt Electrolytic Copper Extraction Process, by Wm. E. Greenawalt.

(4) Electrolytic Zinc from Complex Ores, by U. C. Tainton.

At the Spring Convention of the American Electrochemical Society, Philadelphia, Pa., April 24th to 26th, the following papers were presented:

(1) Review of Progress in Electrolytic Refining of Metals, by S. Skowronski.

(2) Electrodeposition of Copper by the Union Miniere du Haut Katanga, by H. Y. Eagle.

(3) The Electrolytic Tank House, Chile Exploration Co., Chuquicamata, Chile, by C. W. Eichrodt.

(4) Electrolytic Silver Refining at Pachuca, by G. H. Clevenger.

(5) Electrolytic Tin, by Charles L. Mantell.

(6) Electrolytic Refining of Tin, by J. R. Stack.

(7) Progress in Electrolytic Iron, by Donald Belcher.

(8) The Electrolytic Production of Beryllium, by B. S. Hopkins and A. W. Meyer.

(9) Electrodeposition of Tellurium, by F. C. Mathers and H. L. Turner.

(10) An Attempt to Electroplate Tungsten on Iron, by C. A. Mann and H. L. Halvorsen.

There was also a session at which a series of seven papers on applications of organic electrochemistry was presented. The subjects were largely treated in a manner of value to the electrochemist, and therefore while they might be of interest to the electrical engineer if differently treated, a list of these papers is not being recorded.

Of all the electrochemical and electrometallurgical processes in which progress has been made during the past year or two, the one perhaps of greatest interest and possible future value to electrical engineers is that of electrolytic iron. It is worthy of record that the electrolytic production of high grade iron is receiving very great attention in a number of quarters in America, as well as in Europe, and that in America several small but commercial plants are already in operation, the latest of which has been started only within the past few months. Details will probably be available for publication later in the year.

J. L. McK. Yardley, *Chairman.*

IRON AND STEEL INDUSTRY COMMITTEE

To the Board of Directors:

At a meeting of this Committee in September, 1923, at which each member was present, plans for the ensuing year were discussed. It was agreed that the Annual Report should assume the form of either:

A technical paper prepared by members of the committee, dealing with some vital problem of the steel industry, for presentation at joint meetings of the Association of Iron and Steel Electrical Engineers and the American Institute of Electrical Engineers; or,

A Topical Report indicating briefly the progressive development of electrical applications in the steel industry.

The first suggestion had the enthusiastic and unanimous approval of the Committee. The subject selected for the paper, "Economic Balance of Thermal, Electrical, and Mechanical Energy" presents the greatest problem which the engineers of the steel industry have to face. A very comprehensive outline of this paper was prepared under such general subdivisions as:

A Sources of Heat and Power.
- a. Water Power.
- b. Natural Fuels.
- c. Prepared Fuels.

B Direct Application of Heat.
- a. Power Plant.
- b. Coke Ovens.
- c. Blast Furnaces.
- d. Open Hearth.
- e. Soaking Pits.
- f. Reheating Furnaces.

C Direct Application of Power.

D Heat Balance in Typical Steel Plant.
- a. Energy requirements for steel plant of 100,000 net tons per month of finished and semi-finished steel.
- b. Number of 600-ton blast furnaces.
- c. Net tons of ore, coke, and limestone.
- d. Cubic feet of gas evolved.
- e. Cubic feet of gas required for stoves.
- f. Cubic feet of gas available for other purposes.
- g. Capacity of by-product plant to supply coke required by blast furnace.
- h. Cubic feet of available coke oven gas.
- i. Number of 100-ton open hearth furnaces required.
- j. Quantity of gas, oil, or pulverized coal required.
- k. Reclaimed energy from open hearth waste heat boilers.
- l. Equivalent capacity in 50-ton electric furnaces.
- m. Kw. hour and B. t. u. consumption of electric furnaces.
- n. Number and capacity of soaking pits.
- o. Pulverized coal, oil or gas required.
- p. Tons of steel through Blooming Mill. Kw. hours and B. t. u.
- q. Tons of steel through 24 in. Billet and Bar Mill. Kw. hours and B. t. u.

r. Tons of steel through two 18 in. Billet and Bar Mills
Kw. hours and B. t. u.
s. Tons of steel through 14 in. Merchant Mill.
Kw. hours and B. t. u.
t. Tons of steel through 10 in. Rod Mill.
Kw. hours and B. t. u.
u. Estimate of energy for all auxiliaries.
v. Summary expressed in terms of total B. t. u. in coal used for coke or as fuel for direct heating including B. t. u. value for fuel oil, also B. t. u. consumed or reclaimed in each application whether in form of heat or mechanical power.
w. Discussion of purchased power versus local generation.
x. Interconnection with Public Utilities.

Considerable work was done in the accumulation of data for this paper, and an effort made to arrange for joint meetings with the Local Sections of the A. I. E. E. in the more important steel centers. These efforts met with little success and the excellent work of certain members of the committee was rendered useless by the inability of all to devote the necessary time to this difficult but very important subject.

The committee, therefore, reluctantly gave up the preparation of this paper, and can only express the hope that under more favorable circumstances the work may be carried to a successful conclusion.

In place of this proposed technical paper the committee submits the following topical report of developments of the past year.

1. Generating Units

The steam turbine still holds first place as a prime mover in the steel plant power station, although excellent results are being obtained with the slow-speed gas engine using blast furnace gas under local conditions of high-load factor. A combination of gas engines and steam turbines often makes the ideal steel plant generating unit. In some instances the best economy is effected by the purchase of tpower during periods of low-load factor while carrying the base load of the steel plant at high-load factor on gas engines.

Much development work is being done with gratifying results in an effort to perfect the Diesel oil engine for small plants where these requirements do not exceed 5000 kw.

II. Distribution

It is almost impossible to appreciate fully the part which electricity plays in the steel plant of today. Cumbersome and inefficient steam and hydraulic lines are already largely replaced by a distributing network of electrical lines transmitting power to all parts of the plant in any desired quantity from local generating stations or from sources many miles distant. Instead of the many small and relatively inefficient prime movers formerly scattered about the plant, electricity has made possible the high economy of the modern central station, operating independently or in conjunction with other power systems.

If electric power is purchased from a source outside the steel plant, it is obtained at some high voltage such as; 22,000, 33,000, 66,000, etc., and is then stepped down through transformers to the working voltages of 6600 or 2200. The larger steel plants usually generate their own power at 6600 volts, as energy is easily transmitted about the plant with very little loss at this voltage. The 6600-volt power, either 60 or 25-cycle is commonly used for main-roll motors and stepped down through transformers to 230 volts a-c. or through motor-generators or synchronous converters to 230 volts d-c. for use on the smaller auxiliary motors.

Continuity of service through the distributing system, one of the most important, if not *the most important*, factors in a steel plant, seems to be best secured electrically through the use of the so-called loop or ring system, either overhead, underground, or a combination of both. This method of distribution lends itself to segregation of faults by the use of oil circuit breakers for the high voltages; of carbon circuit breakers or magnetic switches for the lower voltages. By controlling the breakers or switches with relays and interlocks, it is possible to isolate automatically any part of the system on which faults occur and without any material disturbance of the load on other parts of the system.

III. Yard Electrification

The economies found in the electrified yards of steam railway lines are found in even a greater degree in the steel yard system, due to the very intermittent nature of the work performed by a switching or transferring locomotive or car.

In a steam-operated yard there are individual self-contained units, generating motive power, handled more or less carelessly, and as a rule, with very low economies. The electrically-operated yard also has many individual self-contained units which, however, take their power from a central station fully equipped to produce power in large quantities at low cost. These electric locomotives with full automatic control are usually in the hands of a single skilled operator and show a very fair operating economy.

The success or failure of an electrified yard depends to a large degree upon the method of getting power to the locomotive. Results obtained to date indicate that yard electrification is best secured through the use of the third-rail method, preferrably the under-running type, of supplying power to the electric locomotive or car rather than the overhead trolley. The under-running third rail can easily be stepped over without personal danger. In a highly congested yard the use of a third rail demands a careful layout of switches, cross-overs, etc., but will adequately meet most requirements. In some cases a combination storage battery and third rail may be desirable.

One of our largest steel plants, after a year's experience with a 40-ton storage battery locomotive in general yard service reports most favorably. This locomotive is in operation during two 8-hour shifts and

is charged during the third shift with occasionally one or two short-time high-current boosts during the 16 hours of continuous operation.

Among the many advantages of electrified yards over steam-operated yards are: one-man operation; no loss of time for getting coal and water or dumping ashes; cost of power about one-third that of steam; maintenance of electric locomotives on the order of one-ninth that of steam; two electric locomotives coupled together and operated by one crew; depreciation of electric locomotive materially less than that of a steam locomotive; greater flexibility in operation.

IV. Electric Furnaces

Thirty-seven new electric furnaces were installed during the year of 1923 in the United States and Canada, bringing the total number installed from 456 on January 1, 1923 to 493 on January 1, 1924. Of this number 442 are in the American industry and 51 in Canada. The new installations are mostly of small capacity, of 5 tons or less. Notable among the larger furnaces is one of 60-ton capacity. Development during the past year has been largely on the arc furnaces. Of the arc furnaces the three-phase, three-electrode type seems to be operating the most satisfactorily.

A number of repulsion-induction brass-melting furnaces was placed in commercial operation during the past year. This type of furnace utilizes the force of electro-magnetic repulsion existing between transformer high tension and low tension windings to cause a circulation of molten metal in the melting pot. A notable accomplishment of this type of furnace was the successful melting of pure copper on a commercial basis.

The largest horizontal single-ring type induction furnace in the United States has a maximum capacity of six tons and in normal service will melt three tons every three hours. It requires 800 kw. at 2200 volts, single-phase, 8½ cycles, supplied from a specially designed synchronous motor-generator. The motor of this set is rated at 1400 kv-a., 3-phase, and is operated at 80 per cent leading power-factor in order to compensate for low power-factor conditions in the electrical systems of the mill. In this way a low power rate is secured and the disadvantages of the inherent low power-factor of induction furnaces are avoided.

V. Electric Heating

Electric heating finds an important application in low-temperature heat treatment of small steel parts. Such installations, however, are more numerous in the steel-products industries than in the steel-making industry.

During the past year, a device has been developed for electrically pre-heating sheet-mill rolls preparatory to rolling hot steel sheets. Methods previously in use involved a series of gas flames, or hot-water jets played on the rolls during the warming-up period. By the use of electric heat, the rolls are more uniformly heated, the warming-up period is shortened, roll breakage is decreased, and a better steel sheet results.

Electric space heaters are now being installed in the frames of rotating machines in order to keep the windings warm and prevent sweating during long periods of idleness. This results in a materially longer life for the insulation, and lessens the danger of breakdown.

During the year 1923 electric ovens were, for the first time, successfully used for the bright annealing of copper wire. The oven is mounted on wheels and is moved back and forth over two hydraulic platforms, one of which can be loaded while the other is in the heating chamber. A water seal keeps the air from this chamber. The wire is uniformly annealed at all points in the oven and the product is bright and free from scale.

The connected load is 300 kw., 550 volts, 3-phase, and 7000 lb. of copper wire can be charged at one time and fully annealed in 75 min., the energy required averaging about 1 kw-hr. for each 25 lb. of wire.

VI. Automatic Control

During the past year there has been a steady movement toward simplified control and improved safety devices but no radical departures from past practise.

The ever-present demand for increased production has resulted in higher speeds for mill cranes and has consequently necessitated particular attention in design to secure safe and accurate control of the loaded hook, as well as high speeds for lowering the hook when empty. This is particularly the case with hot-metal cranes where dynamic braking is being extensively and satisfactorily used. Magnetic holding brakes are, of course, used in addition, one on the motor shaft and one on the intermediate shaft. The higher speeds coming into general use have also brought about the development of a safe limit switch, positive in action yet compact and admitting of mounting in various positions. There is a decided and increasing tendency toward the use of enclosing features as a safety measure.

As mentioned elsewhere, the desirable characteristics of the synchronous motor have, in some few instances, overbalanced its objectionable features for steel-mill drives and a new type of automatic pushbutton starter has been developed for these motors which affords better protection and greater convenience than the older type of manual starter.

The use of automatic substations is spreading rapidly in the steel mills and during the last year several papers on this subject were presented before various societies. There is no doubt but that the automatic substation is an important item in the electrical net work of the mill. It is an excellent example of what can be accomplished safely and satisfactorily with automatic control.

Automatic hoists are being installed in the mills for handling coal, ashes and similar material. Balanced

and unbalanced types are used calling for full reverse and dynamic lowering controllers. High-speed operation is provided with adequate slow-down features through automatic controllers. The use of two-speed a-c. motors has been an important addition to this field.

Two blast-furnace skip hoists have been installed recently using standard mill-type motors with mill-type shoe brakes of large size. One has a single motor equipment and is provided with full automatic push-button-operated control. The other uses two motors with a full automatic, series parallel controller to get high-speed operation with adequate slow-down and accurate stop. A large 36 in. shoe-type magnetic brake is used on each motor shaft.

The shoe type of magnetically-operated brake is fast replacing all others. A considerable number ofbrakes of a size larger than ever before attempted has been made with wheels 36 in. in diameter and 12 ½ in. face which have been very successful on blast-furnace skip hoists, large cranes, and car dumpers.

The application of magnetic type of friction clutch for use with synchronous motors and other power drives has been extended during the last 12 months.

Too little attention has been given in the purchase of control equipment to the duty cycle which it must meet. A more careful analysis of the time-torque-speed values is of utmost importance if the maximum of satisfaction is to be obtained under operating conditions.

VII. Main-Roll Drives

The reliability and high efficiency of what has come to be known as the steel-mill motor has given it a status such that only in rare cases is the steam engine ever mentioned as a competitor for main roll drives.

During the past year a very considerable part of the equipment sold for driving main rolls, reversing or non-reversing, has been for the purpose of replacing existing steam engines. Twelve units with an aggregate normal continuous rating of 55,500 h. p., including four d-c. reversing motors, supplied from suitable flywheel motor generators, have replaced engines, and one new 40-in. Blooming Mill has been equipped with a 6500-h. p., continuous rated, 50 rev. per min. d-c. reversing motor and flywheel set.

There has been the usual percentage of constant speed induction motors applied to continuous mills, sheet mills, bar mills and 3-high plate mills. Most of these installations are of interest only as an indication of the continuously increasing use of electric power. One installation comprising an 8000-h. p. 240 rev. per min., 13200-volt constant-speed induction motor, driving an interrupted continuous blooming mill, is notable as being the first steel mill motor for operation above 6600 volts.

The use of individual motors for the finishing stands of certain types of continuous mills, with the most exacting speed requirements, is increasing. Thus far the condition has best been met with d-c. motors in spite of their somewhat higher first cost and lower efficiency as compared with a-c. motors. The use of rolls in tandem, operating at high surface speeds and with but a short distance between stands, as in the case of continuous hot-strip mills, has made necessary a design of motor with close inherent regulation over a wide range of speeds. The success of such designs has been fully demonstrated in recent strip-mill installations.

In the normal expansion of an engine-driven plant, it is often desirable to disconnect a part of the rolls and drive them from one or more suitable motors. Due to the poor speed regulation of the engine, it is necessary to use adjustable speed motors provided with a special synchronizing control which will enable the motor automatically to follow closely all variations in engine speed. Several types of such control have been placed in successful operation.

Rolling mill engineers have long desired to apply synchronous motors to main rolls on account of the beneficial effect on the plant power factor. The deficiency of the usual synchronous motor in starting torque, has, however, almost entirely prevented such applications. The development of the revolving frame synchronous motor has overcome this objection and two such motors, each rated 580 kv-a. 70 per cent power-factor (500 h. p.) 360 rev. per min. have been installed for driving copper rolling mills.

An entirely new application and important development are the building of two BTA brush-shifting motors for driving rolling mills. One has a 3 to 1 speed range with 600 h. p. at maximum speed and the other 2 to 1 speed range with 500 h. p. at maximum speed. The operation of these machines will be watched with considerable interest, as they are expected to meet a long-felt need for an adjustable speed a-c. drive where the power required is too small to make Scherbius or Kraemer apparatus feasible on account of their high initial cost in small installations.

The largest Kraemer equipment in this country has been built during the year and will be used to drive a 14-in. Merchant Mill. This equipment is rated 4500/4500 h. p. 500/300 rev. per min. 2200 volts.

An interesting example of the attempt to secure the maximum flexibility in mill design is found in a 20-in. strip mill recently placed in operation. The roughing train is driven by a constant-speed induction motor, the intermediate train by a single adjustable-speed d-c. motor and the three finishing stands are driven by three independent adjustable-speed d-c. motors. The use of synchronous converters for supplying direct current for the adjustable-speed motors represents a departure from the usual steel-mill practise of using motor-generators for this purpose.

The following summary includes only main roll

motors 300 h. p. and above, built by the three principal electrical manufacturers in this country.

		June 1923	June 1924
Continuous h.p.	60 cycle	452,840	478,390
" "	25 "	475,825	490,225
" "	direct current	299,670	324,860
	Total	1,228,335	1,293,475

This shows an increase of 65,140 h. p. in the aggregate of main roll motors supplied by these three companies during the past year.

VIII. Arc Welding

Arc-welding processes and equipment are well standardized. The metallic arc has almost completely supplanted the carbon arc as it has been found that reliable welds can be made by a less skillful operator and the deposition of metal is just as rapid. Arc welding is being extensively used about the steel plant in the repair of worn pinions, wobblers, rolls, driving spindles, etc.

There appears to be a decided tendency toward the use of greater welding currents, and single-operator machines of high capacity are being produced to meet these requirements. The application of automatic arc-welding processes is expanding as the increased production and lower costs obtained become known.

One of the most important achievements has been a marked improvement in the construction of the electrode which makes it easy to combine the desired welding flux within the body of the electrode, thus securing all of the advantages which could be obtained with an externally coated electrode without its disadvantages. The flux is enclosed in an annular space between the core and a sheath, the amount being controlled by the thickness of the annular space.

It is customary to incorporate with the flux of coated electrodes, materials which merely serve as a binder. These materials add to the slag produced making it difficult to avoid inclusions in the deposited metal. The enclosed flux cannot flake off before it actually enters the arc.

The sheath, which receives the current and conducts it to the arc, always presents a clean surface to the holder or current-feeding device. This is particularly advantageous with the automatic welding machine where current is led in through the feed rolls or nozzle, as the electrode wire travels through in a continuous length.

* * * * *

There is a marked interest in the generation of electric power for sale as a means of realizing the benefit from the surplus gas from merchant blast furnaces. The single furnace of the Trumbull-Cliffs Furnace Company at Warren, Ohio has developed approximately 5000 kw. continuously over and above the power required for the plant itself and sold it to the local public service company. This sale of power materially affects the profit per ton of pig iron, placing the merchant furnace on a par with the furnace located at the steel plant, which in the past has been in better position to utilize the excess gas.

F. B. Crosby, *Chairman*.

PROTECTIVE DEVICES COMMITTEE

To the Board of Directors:

In addition to the five subcommittees which have been working during the past few years on protective devices, a new subcommittee on Automatic Stations was authorized and appointed last year and has been doing very active work.

Thus the committee's activities have been carried out along the lines of the six subcommittees, namely:

1. Lightning Arresters
2. Oil Circuit Breakers, Switches and Fuses
3. Relays
4. Automatic Stations
5. Current-Limiting Reactors
6. Grounding of Systems

The dependency on automatic devices on which the central station companies are constantly insisting is becoming stronger each year and the emergency functions are being taken away from the operator and placed with the properly selected equipment which is found more dependable than the human operator. The automatic features are found to be on the job twenty-four hours a day, 365 days in the year and can be relied upon to function in a moment's time and thereby maintain service at a higher standard with less operating cost than a completely manually-operated equipment.

During the past year the committee work has been very well supported and excellent results have been obtained, as indicated in the following subcommittee reports.

Subcommittee on Lightning Arresters

F. L. Hunt, *Chairman*

The work this year of the Lightning Arrester subcommittee has been chiefly that of preparing and agreeing on a statement which may be used as a basis of lightning arrester performance. This has been completed and was published in the June issue of the A. I. E. E. Journal under the title "Basis of Comparison in Lightning Arrester Performance."

This statement is believed to be a start toward standardization in testing and classification of lightning arresters and it is the intention of the sub committee to follow it up by the formulation of definitions of the features brought out in this statement.

The several different angles of lightning arrester design, performance and testing have been brought up in the papers fostered by the subcommittee and presented at the Spring Convention in Birmingham under the authorship of A. L. Atherton, E. R. Stauffacher, W. F. Young, and C. E. Bennett.

During recent years there has been a steady increase in the emphasis which is placed on continuity of service by central stations and as the systems have grown in size and complexity, the results of failures become more serious. This has increased the emphasis and need of more effective protection against lightning and surges which has resulted in improved types of arresters being manufactured.

There is apparently some distance to travel before we find an ideal arrester, although the new developments in the Autovalve and Pellet type of arresters have gone a long way in bringing out an effective and simple arrester.

The necessity of good grounding conditions in connection with lightning arresters has been brought out forcible this year, and attention is called to the fact that even an ideal arrester would be of little value on a system where good grounding conditions were not made effective.

Lightning arresters are very seldom installed today on completely underground systems and there is some question regarding their desirability on high-potential transmission lines of 200,000 volts and above.

Subcommittee on Oil Circuit Breakers, Switches and Fuses

E. C. Stone, *Chairman*

The subcommittee on Circuit Breakers, Switches and Fuses in cooperation with the representatives of the National Electric Light Association and the Electric Power Club have agreed on a definition of the interrupting duty of an oil circuit breaker. This definition as recommended to the A. I. E. E. Standards Committee is—

Interrupting Rating of Oil Circuit Breakers

The interrupting rating of an oil circuit breaker is a rating based upon the highest r. m. s. current at normal voltage that the breaker can interrupt under the operating duty specified.

The value of the current shall be taken during the first half cycle of arc between contacts during the opening stroke.

Operating Duty of Oil Circuit Breakers

(a) The operating duty of an oil circuit breaker shall consist of a specified number of unit operating cycles at stated intervals.

(b) Each unit operating cycle shall consist of a closing of the circuit breaker followed immediately by its opening without purposely delayed action.

Interrupting Performance of Oil Circuit Breakers

(a) An oil circuit breaker shall perform at or within its interrupting rating without emitting flame.

(b) At the end of any performance at or within its interrupting rating, the circuit breaker shall be in the following condition:

(1) *Mechanical*

The breaker shall be substantially in the same mechanical condition as at the beginning.

(2) *Electrical*

The breaker shall be capable of carrying rated voltage, and its main current-carrying parts shall be substantially in the same condition as at the beginning.

After performance at or near its interrupting rating, the interrupting ability of the breaker may be materially reduced and it is not to be inferred that it may be re-closing after such performance without inspecting, and, if necessary, making repairs.

Standard Operating Duty of Oil Circuit Breakers

The standard operating duty of an oil circuit breaker shall consist of two unit operating cycles at a two-minute interval.

The manufacturers are rating all new breakers in accordance with this definition and are also in position to give the rating of their old oil circuit breakers on this basis.

Although there have been no radically new developments in oil circuit breakers during the year and the largest breaker is still limited to 1,500,000-kv-a. rupturing capacity, the manufacturers are considerably advanced in the art and if larger breakers are required we fell reasonably sure that they can be supplied. There has been a marked improvement in the development of oil circuit breakers in the truck or quick removable type, allowing very much better facilities for inspection and repairs. This type of breaker is becoming very popular in the central station industry and will be of considerably greater use in the future.

A number of operating companies has started tests on oil circuit breakers to determine if the ratings guaranteed by the manufacturers are met. The operating industry expects to carry this very much further during the next year and a very definite set of specifications for testing oil circuit breakers so that the different sets of tests may be brought into a comparable basis, has been prepared. While it is expected that experience will possibly result in some modification in detail of this specification, it is believed that it covers the essential points and it is recommended that in order to secure truly comparative results, power companies conduct their oil circuit breaker tests in accordance therewith. Copies of these specifications can be obtained at the A. I. E. E. headquarters.

There has been a distinct improvement in the satisfactory use of high-voltage current interrupting fuses and a number of tests has been conducted showing that it is possible to rely upon fuses in certain places where the short-circuit current does not reach excessively large values.

At a technical session of the Spring Convention at Birmingham, devoted completely to oil circuit breakers, papers were presented by H. J. Scholz, Alabama Power Company, A. J. D. Hilliard, General Electric Company and J. V. Jenks, West Penn Power Company.

Subcommittee on Relays

A. H. Sweetnam, *Chairman*

The Relay Handbook is being published jointly with the National Electric Light Association, as mentioned in last years report. It is practically completed and publication may be expected during this fall. We feel sure that this book fills a need throughout the industry and its publication will be welcomed by all. On account of the large number already subscribed for, there will be 10,000 volumes printed which reduces the price to N. E. L. A. or A. I. E. E. members to $4.00 per single copy with quantity discounts for 100 copies to one address at $3.00 per copy. The price to non-members is 50 per cent above these figures.

Development of greater accuracy of the transformer and the development of lower ampere windings on relay have made it possible to use bushing current transformer for relay protection, thereby saving considerable space and extra investment on new installations.

Greater use is being made of the indicating pointer and targets on the relays. Some companies are using the indicator pointer as an ammeter on the front of the control board. This not only gives them an indication of the load on the feeder but assures them that the relay circuit is intact. The targets have proven very valuable in analyzing troubles showing that a switch tripped out due to relay operation on certain phases.

Of the new type of relays that came out in production last year, the impedance relay is probably the most promising. This relay works on the principle of combining voltage and current with time so as to make the relay operate first which is next to the trouble. Two elements, one of potential and one of current, are so designed and arranged that the time of closing is inversely in proportion to the current and directly proportionate to the voltage or, in other words, depends on the distance between the relay and the fault.

A new relay designed to protect against open-phase, reverse-phase and unbalanced-phase in rotating machinery has been produced and shows promise of good application. This relay combines reactors and resistors in a network with an induction relay so that no current flows through the relay as long as the polyphase service is balanced and the phase rotation is correct. Upon the occurrence of the abnormal condition above mentioned, the relay received an appreciable amount of current and operates.

Greater care has been taken in the testing and maintenance of relays, and to the equipment available for this work has been added the portable phase meter which will indicate in electrical degrees the vector relationship between the current and voltage in any circuit. This addition to the testing equipment will make it possible to give greater assurance in the connections of directional relays.

The adoption of a-c. networks has made it desirable to install in certain places relays in manholes, and although the work in this connection is not very far advanced, there has been considerable emphasis placed on the development of relay cases for installation in moist or water-filled manholes and we can look forward to the development of real equipment for this work during the next year.

Subcommittee on Automatic Stations

W. H. Millan, *Chairman*

The newly organized Subcommittee on Automatic Stations has put in a year of very active work and has brought before the industry the dependability of protective devices for automatic stations in the six papers to be presented at one session of the Annual Convention in Chicago, by C. W. Place, H. L. Wallau, C. A. Butcher, Herman Bany, F. D. Wyatt and R. J. Wensley. The work of the next year has been very definitely laid out and the numerous subdivisions of this subject will be studied in considerable detail for a more comprehensive report next year. It is definitely planned to investigate the possiblity of applying automatic devices to perform all of the functions ordinarily included in the operators' duties even as far as such matters as the leakage of oil from transformer or switch tanks.

Subcommittee on Current-Limiting Reactors

N. L. Pollard, *Chairman*

From the results of this year's study it appears that the reactors have filled the requirements more completely during the past year and reactor failures have been few. The manufacturers of this piece of equipment have studied the special requirements of the tremendous forces and potential strains and have produced a reactor which apparently meets the requirements in every respect.

In order that the special requirements of reactors may be brought before the industry, the committee has prepared a specification for current-limiting reactors which was published in the June issue of the A. I. E. E. Journal. The disputed question of the desirability of using resistors with reactors is apparently no nearer solution than it has been for the past few years. One of the large manufacturers recommends the use and two do not. There has been no operating experience which shows clearly that either the resistances are a hazard or that they are a necessity. The present status of the manufacture has been brought out in the three papers to be presented at the Annual Convention by H. O. Stephens and F. H. Kiersteadt, W. M. Dann, and S. I. Oesterreicher.

Subcommittee on Grounding of Systems

E. R. Stauffacher, *Chairman*

Last year's committee covered the Eastern operating views on grounding of systems and this year's com-

mittee has studied the same problem from the angle on the Pacific Coast.

There is still considerable discussion as to the amount of resistance which should be inserted in the neutral of a system which varies from several hundred ohms down to a solid ground. The very high-voltage systems have in general adopted this solidly grounded neutral and considerable apparatus is specified on that basis. Some of the more moderate transmission systems having 22,000 volts have adopted the solidly grounded neutral last year and there has been considerable extension of the solidly grounded 3-phase, 4-wire distribution system.

HARRY R. WOODROW, *Chairman.*

ELECTRICAL MACHINERY COMMITTEE

To the Board of Directors:

DURING the administrative year 1923-24 the Electrical Machinery Committee has conducted the following activities:

1. *Papers*—Under the direction of the Meetings and Papers Committee, thirty (30) papers have been secured by the Committee for Institute meetings, including the Annual Meeting of this year. These may be grouped as follows:

a.	Factors which influence design of electrical machinery	9 papers
b.	Generator design and construction	9 papers
c.	Motor design and construction	5 papers
d.	Frequency-Converter design and construction	1 paper
e.	Transformer design and construction	5 papers
f.	Static-Condenser design and construction	1 paper
	Total	30 papers

Opinions have been expressed to the effect that the presentation of so large a number of papers is not accompanied by sufficient advantages to justify the heavy expenses associated with their publication. It has to be admitted that any one paper is rarely even read by or could be useful to more than from 20 to 200 people and the publication of 20,000 copies in order that 200 copies or less shall reach the people who will profit by them seems at first thought very wasteful. But any other known method is liable to fail to place copies in the hands of the particular individuals who will make to the community the best return from the knowledge or inspiration received from them. The expenses are greatly reduced by the Institute's present practise of publishing in the JOURNAL merely an abstract of not over four papers (and in some instances merely a statement of the title) accompanied by the statement that a copy of the complete paper will be sent to any member applying for it.

The presentation of these papers and their discussion affords the opportunity for the specialists in the design, construction and operation of electrical machinery to interchange experiences and thereby advance in knowledge and ability.

Several of the papers, as examples of which may be mentioned:

Eddy Current Losses in Armature Conductors
Tooth Pulsations in Rotating Machinery
Harmonics Due to Slot Openings
Shaft Currents in Electric Machines

are of the nature of researches leading to information of which general use is made by all designers until such time as still better and more complete results are made available. In other words, while the discussions bring out valuable criticisms with respect to the assumptions made, the methods of investigation employed and the conclusions drawn, there is general satisfaction at the increase in the store of available knowledge represented by the papers.

A second group of papers (really a sub-division of the first group) describes researches into such characteristics of electrical machinery as require to be analyzed before Standards can be established. We may give the following examples of this group:

Effects of Expansion and Contraction on Insulation of Long Armature Coils.

Effects of Time and Frequency on Insulation Tests of Transformers.

Effect of Altitude on Temperature Rise of Electrical Apparatus.

Temperature Rise of Stationary Electrical Apparatus as Influenced by Radiation, Convection and Altitude.

As examples of a third group of papers may be mentioned:

The Inertaire Transformer.

Recent Advances in the Manufacture and Testing of Static Condensers in Power Sizes.

A New Type of Single-Phase Motor.

A New Synchronous Induction Motor.

In papers of the class of which these are examples, radically novel features of design and operation and novel methods of construction are described. The propositions put forward by the authors of papers in this class generally embody radical alternatives to usual types of machines and in the ensuing discussions the propositions are subjected to careful analysis by specialists in the respective fields.

As a fourth kind may be cited those papers consisting in clear and timely descriptions of especially important installations of machinery. We may take as examples:

65,000-kv-a. Generators at Niagara Falls.

The 35,000-kv-a. Frequency Converter for Hell-Gate Station.

While these descriptions are primarily valuable for record and for reference, the discussions often include valuable opinions with respect to characteristics and features of the designs described and of alternatives preferred or at any rate described by those contributing to the discussion.

2. Committee Deliberations on Matters Referred to It

Various matters are referred to the Committee for opinions or action. Recently the Board's Committee to Review the Technical Activities of the Institute referred its Tentative Report to the members of all technical committees. At a meeting of the Electrical Machinery Committee, the Chairman of the Board's Committee, Mr. Berresford, accepted the Electrical Machinery Committee's invitation to attend and assist the Committee in its consideration of the matter. The parts of the report specifically dealing with the Electrical Machinery Committee are reproduced in the following extracts:

EXTRACTS FROM TENTATIVE REPORT OF COMMITTEE TO REVIEW TECHNICAL ACTIVITIES OF INSTITUTE

1. Committee on Electrical Machinery

Field: Cognizance of all matters in which the dominant factors are the design and construction of devices and machinery for the generation, transformation and translation of electrical energy and the requirements determining design and construction, except where such requirements are specifically otherwise assigned.

Note: The expectable functioning of this committee should be initiatory and determinative in the matters within its province. Subject to the approval of the Board it would have power in all matters arising therein, except such formulation of standards as is the function of the Standards Committee, including those of contact with other bodies and of arrangement for joint action where such is indicated.

Standardization:

In your Committee's opinion, a degree of standardization work by technical committees is not only permissible, but desirable. Composed, as it is, of individuals active and experienced in a given field and associated for the purpose of contact with the operations and possibilities of that field, the need for and the possibilities of standardization therein should first present themselves to the Technical Committee.

There are two steps in the making of a standard—

a. The perception of the possibilities, the evaluation of the desirability and the determination of the degree to which standardization may be practicable, including preliminary formulation.

b. The actual and final formulation of the standard.

Your Committee believes that "a" will best be accomplished by the Technical Committee and "b" under the auspices of the Standards Committee, the working committees of which, under these conditions, would instinctively be composed in large parts of the men responsible for "a".

The Electrical Machinery Committee expressed its agreement with these sections of the Tentative Report of Mr. Berresford's Committee.

3. Committee Consideration of Standardization Matters in Their Initial Stages

In the tentative report of the Board's Committee it is stated that prior to the "actual and final formulation of standards" relating to electrical machinery, there is occasion for the Electrical Machinery Committee to make valuable contributions in "perceiving possibilities," "evaluating the desirability" and "determining the degree to which standardization may be practicable" and also in the "preliminary formulation."

At two meetings of the Electrical Machinery Committee held respectively on the 21st of April and the 5th of June, careful consideration has been given to some matters of considerable importance relating to the basic principles underlying the standardization of electrical machinery. These have included propositions drawn up to more clearly distinguish between "rating" and "service conditions." The whole subject is of such immediate interest as to justify including a review in this Report.

Review. Some ten years ago a general plan of Standardization which had particular reference to Electrical Machinery was adopted by the A. I. E. E. This plan was reasonably in agreement with the I. E. C. proposition and has since been very widely used in America and abroad. With respect to temperature recommendations certain limitations were established. These limitations varied with the class of insulation employed, the type of enclosure of the machine, the nature of the cooling medium and the method specified for the measurement of the temperature. But in a general sense or at any rate as an example, it may be stated that for open-type machines built with Class A insulation and cooled by air, the limiting temperature rise as determined by thermometers applied to prescribed accessible parts was established as 50 degrees. This limiting rise was permitted for places where, and at times when the temperature of the surrounding air did not exceed 40 degrees, with the further limitation that the recommendation only applied to machinery operating in places whose altitude was not more than 1000 meters (3300 feet) above sea level. While this general plan was adopted after much thorough discussion in this country and abroad in which many experienced people participated, the original impetus in America came chiefly from Dr. C. P. Steinmetz, Mr. B. G. Lamme, and Prof. A. E. Kennelly, who at that time applied a great deal of study to the subject of *Standards for Electrical Machinery.* It was not the intention either of those in Europe who contributed to this plan, nor of Steinmetz, Lamme, Kennelly and their associates to advocate these values as anything more than *limits.* They fully realized that in the ordinary course of events a very few machines might occasionally come to be subjected to these limiting conditions simultaneously. They recognized that such simultaneous occurrence of these limiting conditions frequently or for long periods would not be desirable but there appeared no sufficiently simple way of specifically discountenancing such operation at these limits without reducing the limits for *all* machines. This would have resulted in the use of uneconomically large machines for almost all cases in order to avoid rather severe conditions in an almost negligible number of instances. Furthermore in this practically negligible number of instances it was known that any disadvantageous consequence would be simply a reduction in the life expectancy of the machine and would not consist in its failure. Naturally approved

construction in all respects and the use of approved materials are assumed in these statements.

This general standardization proposition has gradually come into very wide use not only in America but abroad. In recent years, however, due partly, it is believed, to gradually losing sight of or mistaking the underlying ideas, a great deal of study has been directed to the development of proposals for utilizing machines frequently and for long periods under conditions which may occasion sustained temperature rises equalling and even exceeding the *fifty degree limit*.

Thus if a consumer's motor was located where the surrounding air never or rarely exceeded 30 degrees, it seemed to him, (and the suggestion was sometimes made to him), that if there were no other limitation, such as stalling load or commutation or mechanical strength, he could advisedly place on the motor any load not occasioning more than 60 degrees rise.

Also if he had knowledge that a certain motor with a 50-degree rating actually on test showed a margin of, say, 7 degrees, the rise at rated load being only 43 degrees instead of the limiting value of 50 degrees, then even if the surrounding air had a temperature of 40 degrees he considered that he could place on the motor a greater load up to the point where he had used up this 7 degrees margin; and if the surrounding air had a temperature of only 30 degrees, he considered that he had a margin of 17 degrees extra rise which he could properly utilize. It should be needless to state that no such interpretations or consequences were contemplated when the system of limits was established. Had it been supposed that such interpretations were liable to become general, it would have been necessary to establish correspondingly lower limits. Indeed it was expressly stated in the Standards that the fact of a surrounding air temperature lower than the limiting temperature of 40 degrees was not to be taken as justification for loads occasioning a temperature rise in excess of the 50 degree limiting rise.

Also with respect to altitude, the original purpose in broadly endorsing the use of machines rated on these principles at any place whose altitude does not exceed 1000 meters (3300 ft.) for carrying the same loads as at sea level, was dictated by the desirability of having a simple basis of rating and it was believed that the few degrees greater temperature rise sustained by a machine carrying a given load at the upper limiting altitude as compared with the sea level rise, would at the most only slightly decrease the life expectancy, especially since it was realized that the coincidence of the occurrence of the conditions of the limiting altitude of 1000 meters and the limiting cooling air temperature of 40 degrees would be extraordinarily rare and it was believed that it would not justify the introduction of correction complications.

But the more general knowledge of the influence of altitude on temperature rise is leading people to observe that their machine is described as adequate to carry its rated load at the limiting altitude of 1000 meters. They add this to their knowledge that at 1000 meters altitude the machine has, at its rated load, a temperature rise greater by, say, 5 degrees, than at sea level. They note that on the occasion of its test at sea level it was only required to come within the limit of 50 degrees rise. They consequently consider that the machine must be regarded by its makers to be adequate to carry loads occasioning 55 degrees rise if the temperature of the surrounding air is not over 40 degrees. They may even go further and conclude that if the temperature of the surrounding air is only 30 degrees there is also available a 10 degree higher rise for that reason, giving them license to impose any load which will not occasion over 65 degrees rise. If, furthermore, instead of having, on test, the limiting rise of 50 degrees the rise was only, say, 43 degrees, they can equally reasonably add this further 7 degrees and conclude that the correspondingly increased load is in accordance with the proposition.

Meanwhile, although not as yet recognized in any way in the Institute Standards, manufacturers have established the practise of entering into undertakings applying to the operation of motors with *off normal circuit conditions*. The following is an example:

> Motors shall operate successfully at rated load and frequency, with voltage not more than 10 per cent above or below the name plate rating, but not necessarily in accordance with the standards established for operation at normal rating.

The user presumably reasons that he wants his motor to operate *successfully*. It is of less importance to him if it is "*not necessarily* in accordance with the standards established for operation at normal rating." Let us take the case of a consumer whose circuit voltage is 220 and who has available a 240 volt motor. If he operates it at its rated load on the 220 volt circuit, (on the security of the above quoted clause), the current will be increased about 9 per cent and the copper loss about 18 per cent. The core loss will be somewhat decreased, so the thermometric temperature rise may be only increased by (let us say) some 5 degrees. But if we add this 5 degrees to the 5 degrees relating to altitude which we have already discussed, then, with a cooling air temperature of only 30 degrees the user will be concluding that he will not be impairing the life expectancy by having his motor carry such loads as will occasion a temperature rise of 70 degrees.

But the average user cannot reasonably be expected to know that the 50 degrees limiting rise by surface thermometers is usually associated with a further rise of some 15 degrees in the insulation in contact with the copper and that this further 15 degrees becomes

$$\frac{70}{50} \times 15 = 21 \text{ degrees}$$

additional when the surface temperature rise is 70 degrees. This 6 degrees further rise together with the

5 degrees further rise for altitude and the 5 degrees further rise assumed to correspond to the *successful* use on a circuit with a voltage 9 per cent lower than that on the name-plate aggregate 16 degrees addition to the "hottest-spot" temperature of 40 + 50 + 15 = 105 degrees which is taken as the *Limiting Hottest Spot Temperature* for Class A Insulation. The hottest-spot temperature corresponding to this *successful* operation thus becomes 105 + 16 = 121 deg.

The well-meant and entirely reasonable and practical standardizing proposition built up by Steinmetz, Lamme, Kennelly and their associates and based on suitable *limits* is thus seen to have become a web of inconsistencies and absurdities when interpreted and amended in ways which could never have been reasonably anticipated.

During the few months immediately preceding his death, Dr. Steinmetz was again directing his close attention to this subject and was suggesting a revision of the general proposition to cope with the new circumstances. It was the privilege of some of us to be working with him in this matter.

One of the tentative propositions to which this has led consists in having two entirely distinct statements relating respectively to Service Conditions and to Rating. The statement relating to Service Conditions aims to present a carefully considered recommendation as to when and where a machine may carry its rated load, (or more than its rated load), and when and where the load should be restricted to values less than the rating.

The plan proceeds from definitions of (1) *usual service conditions,* and (2) *unusual service conditions.* For the former the machinery should be adequate to carry its rated load, but for the latter it *may* sometimes be desirable to restrict the load to values less than the rating. These are *application recommendations,* and are distinct from the *rating,* which is a simple value corresponding to defined test conditions.

If this plan should be employed in a standardizing proposition, it is probable that the text would have to be somewhat different for different kinds of machines. The following text entitled SERVICE CONDITIONS has been suggested as suitable for use in *Standards for Transformers* and is being considered as an alternative to a more usual test.

SERVICE CONDITIONS

Usual Service Conditions: Usual service conditions are those in which none of the limits listed below are exceeded, nor two or more of these limits simultaneously closely approached.

Limits:

1. The temperature of the cooling medium should not exceed 40 deg. cent. for air or 25 deg. cent. for water.
2. The altitude should not exceed 1000 m. (3300 ft.)
3. The voltage should not be more than a specified limiting per cent above or below that set forth on the rating plate.
4. The frequency should not be more than a specified limiting per cent above or below that set forth on the rating plate.
5. The power factor should not differ more than a specified limiting per cent from that guaranteed.
6. The maximum load should not exceed the rated load, in combination with a 24 hour load factor approaching 100 per cent.

Unusual Service Conditions: All other service conditions should be designated as "unusual service conditions." Such would be

(a) If one of the above listed limits is exceeded.

(b) If two or more of those limits are simultaneously closely approached.

APPLICATION RECOMMENDATIONS

Under *Usual Service Conditions,* the apparatus should be expected to carry its rated output.

Where either of the two previously stated classes of *Unusual Service Conditions* occurs, it *may* sometimes be desirable to restrict the output to values less than the rating.

For example, a machine may be required for operation where:

a. The cooling medium frequently and for considerable periods approaches the limiting value and

b. The altitude approaches 1000 meters and

c. The machine is required to operate continuously at rated load for periods approaching 24 hours per day and every day and

d. The voltage differs from the rating plate voltage frequently and for considerable periods by amounts approaching the specified limiting per cent deviation and

e. The frequency differs from the rated value often and for considerable periods by amounts approaching the specified limiting percentage deviation.

The need for special consideration in these matters is apparent when it is pointed out that if the prevailing value of (a), the temperature of the cooling medium is sufficiently low, then other limits may be approached without concern; or as another instance, if (c) the load is very fluctuating, the average load being sufficiently low, then other limits may be reached without concern, etc.

In cases where transformers are operated under technical supervision it will be permissible to make use of special loading instructions furnished by the manufacturer.

For example, the instructions may be in the form of maximum available capacity for different ambient temperatures or for different water temperatures and different rates of water flow for water-cooled types, without the maximum temperature exceeding approved values for continuous operation.

Or, where the nature of the load is fluctuating, heset instructions may permit loads inexcess of those approved for continuous operation but of such a magnitude that the deterioration of the insulating materials is no greater than that resulting from rated load in average ambient temperatures.

H. M. HOBART, *Chairman.*

EDUCATIONAL COMMITTEE

To the Board of Directors:

The outstanding event in the field of engineering education during the past year has been the inauguration by the Society for the Promotion of Engineering Education of a comprehensive project of investigation and development with provision for the active cooperation of the faculties of the engineering colleges, the professional societies, the employing industries, federal and state bureaus of education and other agencies.

It will be recalled that in 1907 the Institute joined with its sister professional societies and the Society for the Promotion of Engineering Education in undertaking a detailed study of engineering education. Finding the task to be beyond their financial resources, this group of societies proposed to the Carnegie Foundation for the Advancement of Teaching that it take over the problem. After due examination of the project, the Foundation generously acceded to the request and finally selected Dr. Charles R. Mann to make an extended investigation and report.

The report appeared just as the nation was developing its maximum war effort. The resulting disturbances in the work of the colleges assisted educational progress in details but retarded fundamental changes. As normal conditions returned it was apparent that the broader problems remained as before, plus the added complications arising from the war. It seemed necessary to supplement Dr. Mann's report by gathering additional evidence in order to deal intelligently with both the old and new problems confronting the colleges.

Through the generosity of the Carnegie Corporation the Society for the Promotion of Engineering Education has been enabled to undertake (1) a project for the cooperative gathering of evidence from the past experience of the engineering colleges; (2) a survey of the occupational demands confronting the schools, to be carried out in cooperation with the organized industries and professional societies; (3) a study of the ways and means by which the engineering schools may be effectively related to the organized life of the engineering profession; (4) a study of recent advances in the principles and practises of education and psychology which are adaptable to the work of engineering schools; and (5) a study of corresponding problems and activities in Europe.

An important part in this project is being taken by the national engineering societies. At its 1923 convention the Society for the Promotion of Engineering Education voted to invite the four founder societies to appoint advisory councillors on education who should confer with the Board of Investigation and Coordination having the oversight of the general project. All four societies accepted the suggestion. The Institute appointed Messrs. Gano Dunn and F. B. Jewett to serve as councillors and the other societies named men of equal distinction and ability. The Board of Investigation and Coordination held a conference with the councillors, to which the secretaries of the four societies were also invited, on May 15, 1924.

The conference group recognized that its function is purely advisory and formulated agenda of studies to be pursued rather than action to be accomplished. The present circumstances seem particularly favorable to an inquiry into the professional status of engineering and the implications which arise from it with regard to engineering education. In recent years there has been a strong trend toward standardization in professional education for medicine, dentistry and law. In each case the respective groups of schools and related national professional associations have set up joint agencies of educational standardization. This movement has been closely related to the comprehensive investigations conducted by the Carnegie Foundation for the Advancement of Teaching and has been productive of important gains in the standards of educational preparation for these professions. On the other hand, there have been some results at least temporarily less beneficial.

With a comprehensive study of engineering education now in progress, it is fitting that these movements in other professions should be studied under the joint auspices of the schools and the professional bodies with an entirely open mind. It seems evident that engineering occupies a professional status dissimilar in important respects to the older, highly individualized professions of divinity, medicine and law, and that the formal relations between education and professional life which have been built up in these professional fields, do not necessarily constitute precedents of compelling logic. It is equally true that the national engineering societies might lend a far greater body of support to the engineering colleges without any trespass on their independence or autonomy.

As a step toward the clearer understanding of these problems, the conference group has agreed to sponsor and direct studies of the following subjects, to be carried out by the staff of the Director of Investigations of the Society for the Promotion of Engineering Education:

1. The criteria of professional status, with a view to defining more accurately the status of the professional engineer.

2. The present status of relations between other professional bodies, particularly those concerned with medicine, dentistry, law and architecture, and the corresponding groups of professional schools, including

the background of the present schemes of standardization and rating of schools by professional bodies, the evidences of detrimental as well as beneficial results from such standardization, and the present state of relations between engineering schools and engineering societies abroad, particularly in Great Britain and Germany.

3. Minimum standards which may properly be established for the recognition of any institution as an engineering school or any course of study as an engineering course.

4. Standards of educational attainment, in other than technological fields, which should underlie the professional training of engineering students. This would include languages, history, literature, economics and psychological and sociological sciences.

5. Standards of educational attainment in the common group of mathematical and physical sciences and of technological studies which should underlie the professional training of engineering students.

6. Sanctions concerning the normal length and the degree of specialization of engineering curricula to which the societies represented may be willing to give support.

7. Sanctions concerning the desirable qualifications of teachers who deal with professional engineering subjects, their professional and economic status and the appropriate scale of compensation for engineering teachers, to which the societies represented may be willing to give support.

8. The determination of aptitudes as a basis for admission to engineering colleges.

9. The extent to which the relations of the professional engineering societies to affiliated student groups may advantageously be unified or coordinated.

10. The contributions which the profession-at-large and the business and industrial organizations closely allied to it may make to the fund of vocational information relating to engineering and the means which may be employed to bring such information to the attention of parents, teachers and students at the time of selection of a college or university and of a course of general or professional college study.

11. The recognition to be given to graduation from an engineering college in the requirements for admission to professional engineering societies.

12. A survey of the occupational demand for engineering graduates in the more distinctly professional fields, as a complement to the surveys of demand in industrial fields now being undertaken.

W. E. Wickenden, *Chairman*,

ELECTROPHYSICS COMMITTEE

To the Board of Directors:

Advances in Electrophysics 1923-1924

No attempt will be made to point out outstanding advances for the past year. Progress, in general, is continuous and not in marked steps. For this reason, it has been the policy of this committee to keep the membership informed by means of lectures by noted physicists and research workers rather than by an annual catalog of steps in progress. Such lectures have taken place during the year on general and specialized subjects. It has also been our policy to arrange popular lectures or reviews on the latest status of electrophysics. These lectures have probably always been better attended than those on any other subject. In passing, it may not be out of place to mention that wonderful advance has been made in the past few years in the knowledge of the interior of the atom and the radiations or energy changes that occur from its very heart. It is suggested that the committee next year arrange a popular lecture covering the latest knowledge of the atom.

Lectures and Papers

During the past year the Electrophysics Committee has had technical sessions at the Pacific Coast, the Midwinter, the Annual and the Regional Conventions. All of these sessions have been very well attended and the discussions have been at least as extensive as those at any other technical sessions.

The papers have been on a large variety of subjects such as insulation, transmission, ionization, magnetics, heat convection, transients and oscillations, vacuum tubes and detectors, radio and mathematics.

The committee expects an especially interesting session at the coming Pacific Coast Convention.

It is hoped that our Institute will continue to encourage this work.

F. W. Peek, Jr., *Chairman*.

(*To be continued*)

PERFORMANCE OF ELECTRIC BRASS FURNACES

The number of kilowatt-hours per ton required to melt a given alloy under given conditions is helpful in comparing the performance of different electric furnaces among themselves, state Interior Department investigators in Serial 2597, "Present tendencies in electric brass-furnace practise," just issued by the Bureau of Mines. In comparing electric furnaces with fuel-fired furnaces, the price paid for electric energy must be considered. In the early days of electric brass melting it was unlikely to compete with fuel when power cost over 1 cent per kilowatt-hour. With the development of the more efficient furnaces and the change in cost of fuel, it is today rare that an efficient electric furnace can not compete on 2-cent power.

It generally happens when the location of a foundry makes the price of electric energy high, or when the count of energy used by a small electric furnace is so little that a low rate per kilowatt-hour is not obtainable, that the factors of location and small-scale operation make the cost of melting by fuel correspondingly high.

Discussion at Midwinter Convention

DISCUSSION AT MIDWINTER CONVENTION

(*Continued from page 882*)

R. C. Bergvall: Our papers show a method of determining the maximum amount of power which can be transmitted with a load gradually applied. Mr. Moreland has incorrectly inferred that we propose to *rate* a transmission system as being capable of carrying this amount of power under normal operating conditions. The maximum amount of power which can be transmitted under steady state conditions can only be used as a basis for forming an engineering judgment as to the amount of power which should be transmitted over a given system. The point at which a transmission line should be worked will depend on local factors such as continuity of service requirements, a discussion of these factors being obviously outside of the scope of this paper.

During transient conditions there are so many variables, which would have to be taken into account, including the action of machine governors, which has not been considered by Mr. Moreland, that the reliability of any transient mathematical analysis is open to a great deal of question. The analysis carried out by Mr. Moreland and his associates which show that the *rate of change of load* instead of the amount of suddenly applied load is the important factor, is not borne out by practical operating experience or by our tests. There are numerous cases of two transmission lines operating in parallel where a 100 per cent increase in load results on one of the lines whenever the second line is tripped out and pull-out does not result. In one case where the load thus added to the second line approached the maximum power limit, the system occasionally pulled out of step after two or three seconds, thus indicating that the process is a slow one.

Mr. Moreland has stated that the loads in our tests were gradually applied, basing his conclusion on the oscillogram shown by Fig. 18. This oscillogram does not refer to the suddenly applied load tests as may be ascertained by reading the test data. This oscillogram shows the pull out taking place as the load is *gradually* increased. The suddenly applied load tests were made by intermittently shunting out a portion of the resistance used as load. The inductance of the armature of the direct-current generator of the motor-generator set is very low as compared to the resistance in the load so that the resulting time constant is negligible. Calculations taking into account the inertia of the motor-generator set show that the load variation would be applied to the system in from 1/20 to 1/10 of a second. The results of this test do not agree with the conclusions arrived at by Mr. Moreland and his associates, as to the effect of suddenly applied loads.

The amount of load which can be suddenly applied without causing pull-out to occur can be approximately determined by considering that the synchronous machine excitation remains constant, due to the inductance of its field, resulting in a drop in the receiver voltage. As an example, refer to Fig. 5 in our paper. Assume that the line is carrying 80,000 kw. at 100 per cent voltage, which corresponds to a synchronous condenser excitation of 155 amperes. If the load is suddenly increased to 87,500 kw. and the excitation of the synchronous condenser remains constant, the voltage would drop to point *D* or 58 per cent voltage, resulting in pull out. Mr. Moreland assumes that we would continue out at 100 per cent voltage and could therefore, stand a swing to 107,000 kw. instead of 87,500 kw. without pull out taking place.

The assumption of constant synchronous condenser excitation is, if anything, pessimistic because the armature reactance during transient conditions is in such a direction as to assist the synchronous condenser voltage regulator in increasing the field current. Mr. Evans, in his discussion of Mr. Thomas' paper, presented our ideas of a method for determining the rating of a transmission line and the results are in substantial agreement with those of the other speakers, whereas Mr. Moreland's discussion would make it appear that our results would be widely different from theirs.

Our calculations were based on a constant voltage at the generator end of the line as stated in the paper. This, of course, would only be approached for a very large generating station as compared to the transmission line connected to it. The generator used in our tests was somewhat larger than the maximum load of our transmission line and our tests indicate that for this condition the effect of generator synchronous reactance was small. However, in most practical cases it will be necessary to take into account the generator synchronous reactance by merely adding it to the reactance of the line and considering the internal voltage of the generator instead of the supply voltage of the transmission line. Our method of calculation may readily be extended to meet such condition.

R. D. Evans: Mr. Thomas, in his paper on "Superpower Transmission" has sought to fix a rating of a 500-mile transmission line. Mr. Thomas states that the maximum permissible load on the line is 143,000 kw., and he proposes to operate the

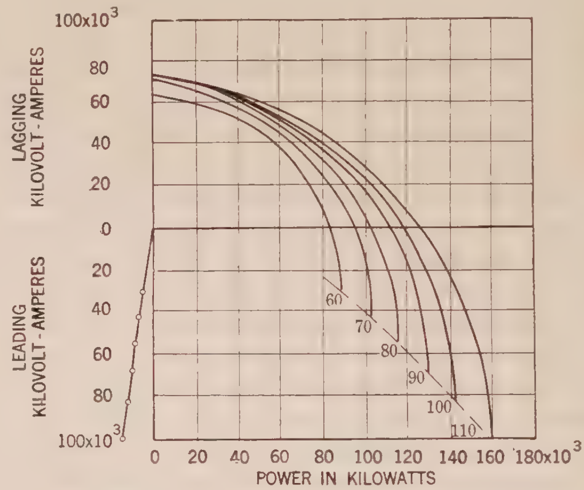

Fig. 48—Circle Diagram for 500-Mile Transmission Line

line at 120,000 kw. continuously when one of the transmission lines is out of service. We do not find that Mr. Thomas made any allowance for the characteristics of synchronous condensers and load which would reduce the maximum permissible output of the line to an amount not exceeding 100,000 kw., and, in our opinion, this amount should be considerably lower to allow a reasonable factor of safety.

We have made calculations, taking into account the characteristics of the synchronous condenser and load, using the transmission line, synchronous-condenser capacity, et cetera, as given in Mr. Thomas' paper. The performance of the transmission line is shown in the circle diagram given in Fig. 4, Condition *A* of Mr. Thomas' paper. A family of power circles derived thereform is reproduced in Fig. 48. The synchronous-condenser capacity is based on 75,000 kv-a. in condensers per line with spares, the condensers having equal leading and lagging kv-a. range. Under emergency conditions, with one transmission line out of service, the condenser capacity per circuit with all the spare units in operation, amounts to 125,000 kv-a. per line, as indicated in Mr. Thomas' Fig. 5.

Mr. Thomas assumes the power factor of the load as 85 per cent. The characteristics of the load for changes in voltage are not indicated, but a reasonable assumption would be that 70 per cent of the load consists of rotating machines of essentially

constant power characteristics. The remainder of the load is assumed as a lighting or resistance load which varies approximately as the square of the voltage. It has been assumed that the reactive kv-a. of the load remains substantially constant, independent of the voltage. Referring to Fig. 49 the curves in solid lines show how the reactive kv-a. required by the line varies with voltage for loads corresponding to the amounts indicated, at 100 per cent voltage; that is, these curves take into account the decrease in power due to the decrease in resistance load with lower voltage. The dotted-line curves show how the reactive kv-a. of the load and synchronous condensers varies with voltage at various constant condenser field excitations. The line *A B* is the locus of points of tangency between the two families of curves. The system will pull out of step when the conditions of operation fall below the line *A B*.

In the actual operation of transmission lines, even in large systems, there are inevitably many sudden fluctuations of load due to short circuits and switching operations either on the main lines or on auxiliary lines or systems tied in therewith. When the load on a transmission line is suddenly increased, the inertia of the rotating apparatus will momentarily supply part of the

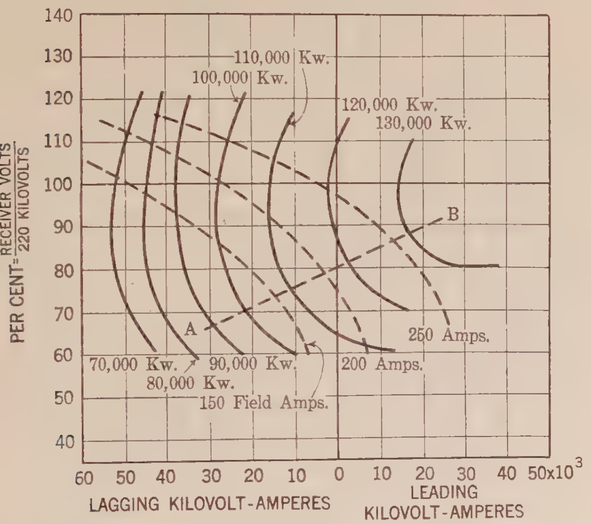

Fig. 49—500-Mile Transmission Line with 125,000-Kv-a. in Synchronous Condensers

additional load requirements. Even allowing for the load increment momentarily taken by the rotating apparatus, a 15 per cent sudden increase in power which the line must supply is a small alowance to make for sudden increase of load due to loss of a transmission line or other disturbing condition. Applying this test to the curves shown in the Fig. 49, it will be noted that if the transmission line is operated at a load of about 101,000 kw., corresponding to a condenser excitation of 200 amperes, pull-out will occur with about 15 per cent increase of load.

Mr. Thomas has tacitly assumed that the line is stable up to the maximum power capacity of 143,000 kw. He has taken no account of the characteristics of the load and synchronous condensers, or of the fact that the machine exictation will not be varied as rapidly as the load can change.

The above analysis indicates a maximum permissible load of 100,000 kw. beyond which there is no certainty of securing stable operation and which must be reduced to allow for the necessary margin of safety. Assuming a 20 per cent margin, the capacity of the line would be reduced to about 80,000 kw.

It is to be pointed out that assumptions have been made which are favorable to the transmission of a large amount of power. For example, our calculations of the transmission-line constants for the particular conductor described by Mr. Thomas show a power limit of approximately 10 per cent below that stated by him and assumed in the preceding discussion. The condenser capacity assumed is very liberal, taking all the spare units in operation. The assumption that 30 per cent of the total load is lighting and resistance load varying with the square of the voltage is also liberal. Mr. Baum's survey shows that lighting load constitutes about 15 per cent of the total. The effect of generator characteristics in limiting the power output of the line has been neglected. The final assumption made in the preceding discussion was the amount of increase in load that should be provided for. The value selected appears quite small when it is pointed out that with three lines in service, the loss of one transmission line would increase the load on the remaining circuits about 50 per cent.

Our analysis indicates that it is impossible to give a rating to the circuit of 120,000 kw. for continuous operation under emergency condition with one line out of service. In our opinion, the maximum permissible amount of power would be of the order of 70,000 to 80,000 kw.

The importance of a consideration of the characteristics of the synchronous condenser and load is emphasized by the fact that the transmission line in Mr. Thomas' paper should not be expected to carry more than about 80,000 kw.

E. B. Shand: My paper on the subject of the maximum output of transmission systems has been the result of a study made several years ago on the principles of stability of synchronous generators both under the condition of constant excitation, and also when the terminal voltage is maintained constant by means of a vibrating regulator. This study gave rise to the distinctions of inherent and artificial stability as defined in the paper. No thought of applying these principles to transmission systems had occurred to me until the proposal of F. G. Baum in 1921 to use synchronous condensers to regulate the voltage at intermediate points of lines suggested itself as permitting a broad extension of the same principles.

On account of the absence of any experimental data regarding the relative speeds of regulator action and of inertia changes in regulated machines, the writer considered it probable that the maximum steady load with a vibrating regulator would be somewhat in excess of the limit determined by inherent conditions; but on account of sudden load increases, where it was appreciated that the regulator action would be too sluggish, he proposed the maximum load as determined by the excitation values of the machines preceding the load increase as the criterion of stability, that is, inherent condition of stability.

With this conception of the problem in mind, he evolved a method for the determination of the limitation of inherent stability of a system utilizing the actual characteristics of the synchronous condenser and of the load. As far as his information extends he believes that this was something entirely new in the study of transmission systems.

At the close of this work the writer came in contact with the power-circle diagram as developed by Messrs. Evans, Sels and Fortescue, and an actual system was investigated using this as a basis. Further study, however, convinced him that the voltage vector diagrams expressed the conditions of stability with greater significance so that this type of diagram was used in the presentation of the paper.

The tests described in the paper of Messrs. Evans and Bergvall, which were made some time later, were of special interest from the writer's standpoint, for they demonstrated definitely that with the vibrating regulator as now developed and with the relative magnitudes of machine inertia as used on the tests, the possible range of artificial stability was negligible. It has been noted that the criterion of stability had already been proposed on the basis of inherent stability, therefore, the result of these tests laid additional emphasis on the importance of this limitation. The co-operated endeavors of the authors of the various transmission papers, both before and after these tests,

cleared up many other questions regarding the operation of transmission systems and their limitations. This is believed to be evident from the papers themselves.

Some of the above discussion, although somewhat recapitulatory, has been included particularly with respect to the discussion by a number of the members,—Messrs. Moreland, Booth, Bush, Doherty, etc., regarding the steady-state stability and surge stability. From additional and more careful reading of this discussion, it seems that a part of their criticism at least is due to a misapprehension or perhaps a mis-application of the data given in the papers. Although the papers referred to take no definite account of transient effects such as inertia, etc., in their calculations, the writer most certainly agrees that in the case of a sudden increase of load the limit of stability will depend mainly on the excitation values of the machines considered prior to the increase of load and not the values required to maintain the proper voltage after the increase. The writer had never comprehended that this point was in question.

Referring now particularly to my own paper, the sole question discussed was that of maximum output, and neither (a) the maximum permissible load, nor (b) the maximum rated load

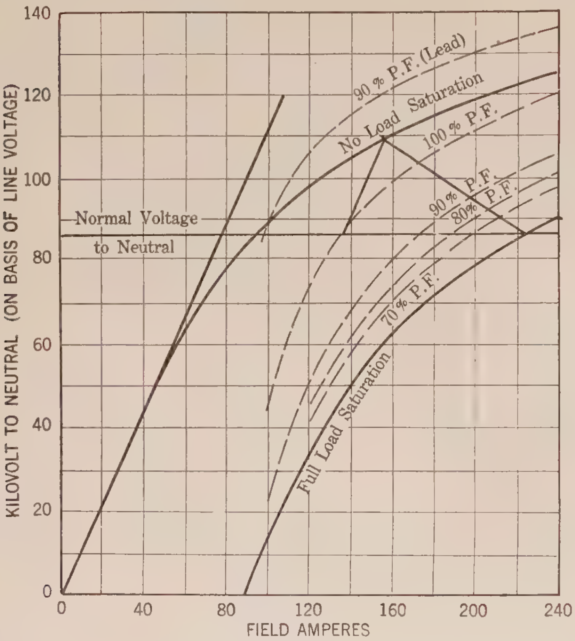

Fig. 50—Characteristic Curves of an A-C. Generator Connected to a Transmission Line

was considered, the purpose of the paper being rather to explain the one phenomenon discussed. The results of examples serve, therefore, as criteria of design, that is, they represent a definite limitation determined by the system itself and not by a combination of variable conditions of operation. The rated capacity on the other hand, is a quantity which may be chosen to give satisfactory results over a more or less restricted range which represents a balance between capital cost and reliability. It may be pointed out, therefore, that a single margin, or factor of safety, might be as judicially chosen as the amount of sudden load increase to be used in determining a new limitation to which a new factor of safety must be added to obtain either a safe maximum load or the rated capacity. Of the two methods of procedure above outlined the writer prefers the former, although to determine a suitable margin it has been his practise to determine the maximum limit of stability under reduced excitation, for instance, that corresponding to normal load on the line, which will, it is believed, check roughly with the methods referred to in the discussion. Fig. 10 of my paper represents the method referred to for the special case of maximum excitation on the synchronous condensers. It will be observed that pull-out occurs at reduced voltages.

Messrs. Moreland and Bush have strongly recommended the inclusion of inertia and field transient effects in calculations. Until these gentlemen have given us the details of their methods it is impossible to discuss them fully. While it would undoubtedly be desirable to include these factors, the writer feels that these members have over-estimated the importance of these factors, and under-estimated the difficulties of accurately taking them into account, particularly in the case of the more complicated types of systems.

Mr. Doherty has censured the writer for his neglect of the effect of generator reactance in the examples of his paper and I have already admitted culpability in the matter. It is only fair to state, however, that if Mr. Doherty had continued his quotation from my paper it would have been evident that the matter was not passed entirely by. Since the presentation of the paper,

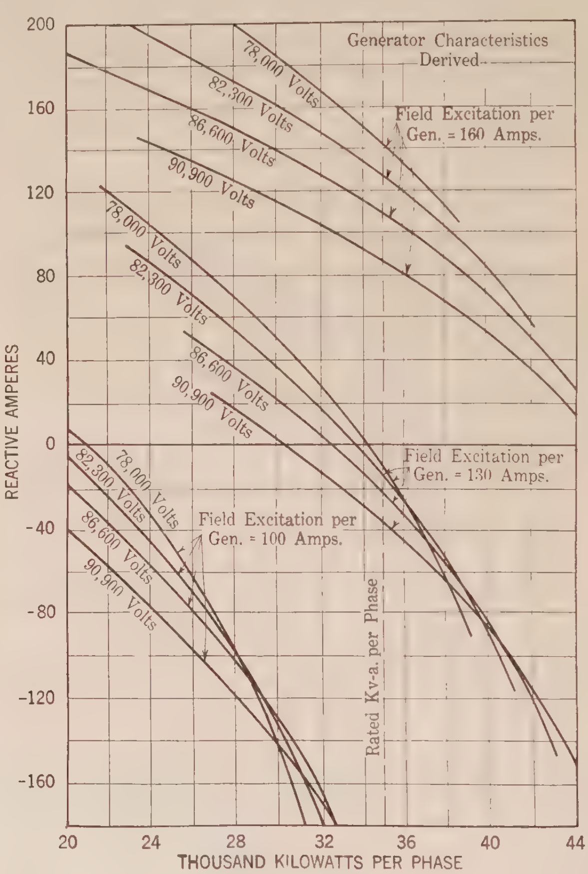

Fig. 51

however, I have extended the diagrams to which he referred, to include the effect of generator reactance. This was accomplished by the first of the two methods referred to in my paper, because the second will prove inaccurate unless great care is used in the choice of synchronous impedance to represent a given machine.

Fig. 50 represents in the conventional manner, the electrical characteristics of the generators considered. The total full-load rating of all the generators combined was assumed to be 35,000 k-va. per phase or 105,000 k-va. total. Fig. 51 gives these same characteristics replotted in accordance with the conventions used in the paper. Three separate values of field excitation are represented. The characteristics of the same compound line of Fig. 12 of my paper, represented by Fig. 52 are derived from an extension of the general method employed for compound transmission lines. All condensers are assumed to be operating under maximum excitation, which is constant regardless of the

voltage conditions at the various points regulated. As a matter of fact, the voltage at the mid-point comes out slightly above normal value which tends to increase the effect of generator impedance slightly. It also causes the generator excitation to be somewhat less than it would otherwise be.

The superposition of the generator characteristics on those of

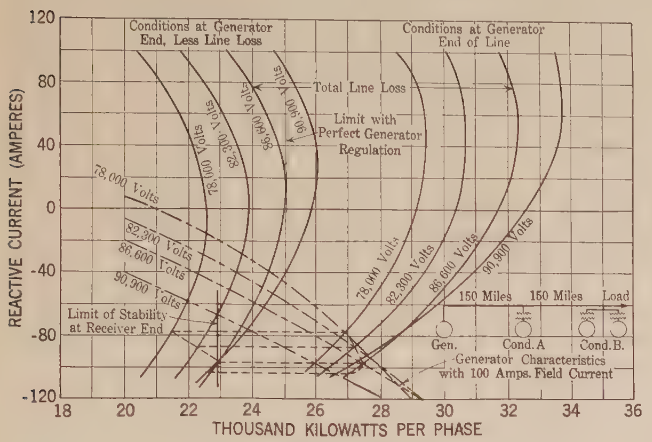

Fig. 52

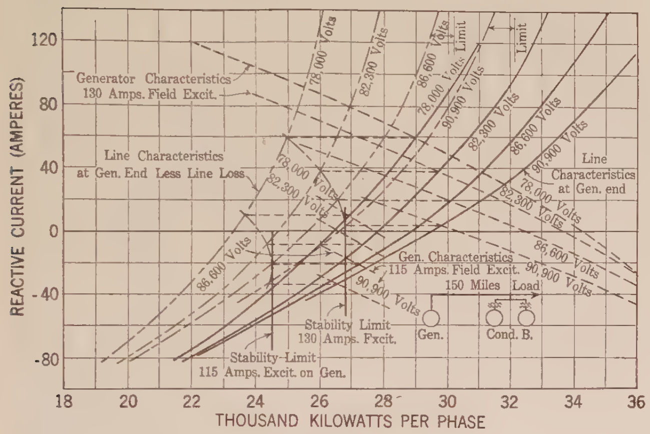

Fig. 53

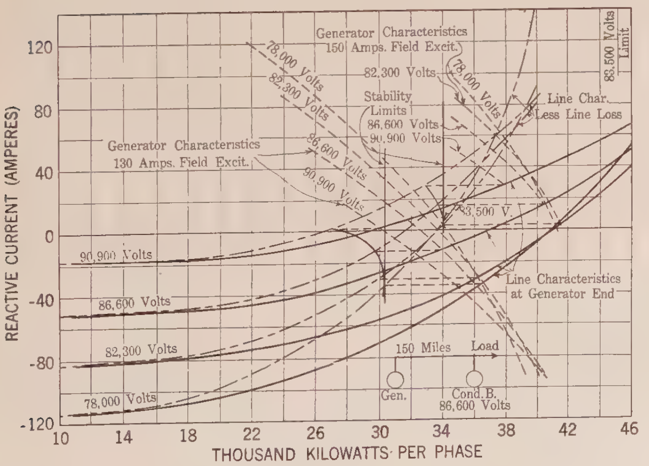

Fig. 54

the line allows the operating condition of the combination to be determined. With a generator field of 100 amperes, the point of maximum output at the receiver end occurs at approximately 86,600 volts at the generator terminals. The load value itself is 22,900 kw. per phase with a power input of 27,400 kw. per phase. The corresponding output with perfect generator regulation is 25,050 kw. which is the same value as that given in the paper. The effect of the generator impedance in this case is a reduction of output of 2150 kw. per phase or by 8.5 per cent. Considering that the generators are underloaded, this value will be slightly smaller than what might normally be expected, but in any event the effect should not be greater than 10 per cent.

Fig. 53 has been plotted to indicate the corresponding effect on a simple line of one half the length of that used above, the rated condenser capacity at the receiver end being 50,000 kv-a. as before. In this case the generator impedance reduces the maximum output from 30,200 kw. to 24,500 kw. which is a reduction of 19 per cent.

A third case, Fig. 54, assumes the conditions to be the same as in the last case except that the receiver end is perfectly regulated. The effect of generator impedance will then be approximately 33 per cent.

This successive increase in the effect of generator impedance is quite to be expected as each change is equivalent to a reduction in line impedance while the generator impedance remains practically constant.

The general conclusion from this investigation is that for transmission lines of the length of those considered in the papers and discussion the effect of generator impedance should be of the general magnitude of 10 per cent reduction of output and that this will naturally increase as the line is reduced in length.

Mr. Terman has brought up in his discussion a point of technicality regarding the conventions in plotting power-circle diagrams. While this is perhaps of minor importance it may be noted that Figs. 14 and 15 in the appendix of my paper comply with his suggestions.

C. L. Fortescue: I thought I had read my own paper over very carefully, but it appears from the remarks made by Mr. Moreland and Mr. Booth and Dr. Bush that I haven't. However, in rebuttal of their accusations I want to point out that it is an entirely different thing to make a hypothetical load in a paper as a basis for comparison and to advocate it as a proper rating.

Now, Mr. Moreland intimates that we advocated a certain rating which was an impractical rating on a transmission line. We have not done so. We have merely taken a hypothetical rating to form a basis of comparison between two different systems: one, a system of 500 miles straightaway, and the other one, 500 miles in length loaded at a middle point. That is quite an appropriate thing to do.

As regards the question of rating, I have always taken this point of view: I say, let's figure up the stability under the worst possible conditions and call these emergency conditions. Let's take a good margin of safety and then under normal operating conditions we shall be good and safe. That is the position I take.

Now, I am an optimist, and I saw a passage in a recent book by Havelock Ellis, in which he says, "The nice balance between optimism and pessimism is the best thing." I think Mr. Moreland and his associates have gone to the other extreme. They are indulging in a great deal of pessimism. They have done a lot of work and hard digging, but it is all theoretical work, and they haven't shown the way they obtained their results. They have shown us a number of curves but how did they get these curves? I hope that Mr. Moreland and his associates will sometime tell us how these curves were obtained.

We, as an actual matter of fact, made tests on a system that imitated on a small scale a 500-mile straightaway line; also a 500-mile line loaded at its middle point, and with this system we had ordinary generators of fair size. We took generators of approximately 500-kw. capacity which at that time we considered would give a fair basis of comparison with those used on large transmission lines.

Now, we supposed it fair to assume that the inertia conditions in those generators and synchronous condensers and also their

synchronous reactance were about on the same scale as these quantities for the generators and synchronous reactors used on an actual 500-mile, 220-kv. line. Under the test conditions we were able to throw off and on blocks of power, 25 per cent of the maximum power which was obtained over that line without throwing the synchronous condensers out of step. These are actual results. I feel a whole lot more optimistic about the problem than Mr. Moreland and his associates.

As regards Mr. Doherty's discussion, I think he has given us a splendid one. He has pointed out that there are other factors that enter into the problem which should be considered. I tried to present the fact that while we, so as to simplify the problem, used the usual convention of ignoring certain factors that we considered did not enter into the problem sufficiently to affect the results, properly speaking, we should have also considered these factors. In other words, I think it is important to get as complete a solution of the problem as possible, and as I pointed out, by the analytical method you can go as far as you please, provided you have sufficient perseverance.

Professor Karapetoff says that the doctors do not agree. He is wrong. The doctors do agree. The only point of difference is the extent to which we should consider all the factors that enter into this problem.

I don't disagree with Mr. Doherty and Mr. Summerhayes in the essentials of the problem. I think we ought to take all the factors into account. We ought to take them into account to see how much they influence the problem, and we shall do so as soon as we can get time.

Percy H. Thomas: All the papers except the first, and most of the discussion treat of the conditions of theoretical stability of a hypothetical *single-circuit* transmission line of *extraordinary length* taken as the *sole supply of power* for a system of distribution containing a mixed load such as is supplied by the usual public utility system.

All are agreed that such a line is capable of carrying certain large blocks of power with 220 kv. maintained at each end, provided the power factor of the passing power at each end has a suitable value. This value of power factor will be different for each value of power transmitted and the line will not transmit this amount of power with the 220 kv. at each end at any other power factor. There is no difference of opinion about this.

Now the line itself has no control over the power factor of the load which it is expected to carry, so that some means must be provided to keep the power factor of the load at the right value for the particular load passing at the moment. Furthermore, the generator must be able to accept the load at 220 kv. at the power factor at which it is brought to the generator by the line.

If either of these conditions is not met, the particular required amount of power will not be transmitted. This power of adjusting the power factor to the proper value to suit the momentary conditions is naturally the function of synchronous apparatus, the generator at one end and a synchronous condenser or another generator at the other end, which *tends* to accomplish this result automatically. So the ability of the system as a whole to carry the load depends directly on the performance of the generator and the synchronous condensers.

Now it so happens that the designers of such apparatus have for sometime been doing their best to build machines that will deliver a minimum amount of arc kv-a. on short circuit, relying on automatic voltage regulators to maintain voltage with varying load. This tendency in design is emphasized since it makes a cheaper machine. But this characteristic of a small short-circuit current is directly opposed to the ability of a generator or condenser to control power factor as required by the *long line.* Furthermore, the action of voltage regulators in readjusting voltages of the machines is too slow (as these systems now operate) to satisfy the line requirements and a second or two of hyatus occurs. Naturally, therefore, when the authors of the papers attempted to determine the performance of the long-line system as a whole, using the electrical performance of commercial machines designed to limit short circuit, the latter were found to be inadequate so that the system as a whole would refuse to transmit the full amount of power expected, at least until regulators had time to act.

These principles and methods of analysis and mathematical and graphical treatment therefore have been beautifully and thoroughly worked out in these papers and have been materially extended by the discussion. The report of tests on a model system is an addition of great value. But after all, the importance of the limitation developed in the transmission system may easily be over emphasized, and wrong impression is perhaps created by the unqualified statements frequently here made that the capacity of a 500-mile line is only so and so much, with or without the midpoint condenser station, etc. In such statements the qualification should have been added, that it is assumed that present commercial designs of machines developed for another service are used, and that a single circuit, or its equivalent is used, without other means of connecting the supply with the load network. These limitations are of the greatest importance as will be seen in a moment.

Returning now to my own paper, I would like to point out that the object of this paper was to cover in a broad way all the pertinent characteristics of an isolated 500-mile transmission feeding an extended network, taken as a whole. In such a broad consideration it would not be feasible to discuss *in detail* all the new features of design, of which there are many, besides the performance of synchronous apparatus.

In studying this subject I soon discovered the weakness of a single-circuit, heavily loaded long transmission line, which is vulnerable not only when supplied with inadequate condensers but also when *for any reason* the voltage at either one or both ends falls seriously. It will do no good to have a perfect condenser if a short circuit on the line will cause the voltage to drop and the load to be lost and the generator thus be left light-loaded to pull out of step. A broader remedy than a perfect condenser is required.

The layout described in my paper and shown as a one-line diagram in Fig. 5, is proposed as one scheme which is not subject to the limitations of the machines brought out in the papers, at least to anything like the same extent as a single circuit and which further provides for many other likely contingencies not considered by the others,—and naturally so, as they would be outside the scope of their papers. I am sorry that no consideration seems to have been given to the method of meeting the situation that I have proposed. Mr. Goodwin has rightly stated that the great detail in the connection to the network at the receiving end of the line shown in Fig. 5, is introduced because it is an essential part of the layout as a whole.

The features of the layout which give it relative immunity to the effects of limited condensers and accidental voltage disturbances are the following:

1st—Each circuit, of which there are four, with its transformers is an independent unit, electrically speaking, and electrically connected to a separate part of the general network, so that a short on one circuit will not cause a serious drop of voltage on the others and hence will not prevent them from carrying their normal load and a certain amount of overload, for a very considerable margin of overload is allowed in the system of my paper. This overload capacity together with the generators in the *receiving network* will be able to do the duty of the affected line.

2nd—After all, the effect of a drop in voltage or of an increase in load which are taken as fatal to synchronism in the limited single-circuit transmission considered in the other papers, unless very severe, is not to cause the circuit to drop all the load from the affected line, but perhaps to drop 10 or 15 or 20 per cent of the load, which can easily be taken up by the other circuits in Fig. 5, provided they all stay in synchronism.

3rd—If we assume large generating capacity in the network, this will go far to relieve the transmission line of its burdens. For example, suppose a big generator or two drops out in the network throwing an additional load on the rest of the system, which is the worst case that is assumed. This will not primarily cause a great drop in voltage per se (if unaccompanied by a short circuit) and the added load will be taken up by the other network generators. It is sufficient in preserving synchronism for the transmission line to carry the same load as before. In any case, any showing down of the system as a whole, will be slow on account of the very small excess load and the large flywheel effect and the voltage regulators will have time to act to restore any drop in voltage.

4th—The condensers of Fig. 5 cannot fall out of step readily because they are all on the same bus bar—similarly with the auxiliary bus at the generator station. This keeps all generators in synchronous operation through any disturbance on any one line.

5th—Four generators or four condensers are available to support any one circuit in case of need, instead of only one condenser per circuit as is considered for single-circuit operation.

Finally, it may be pointed out that much may be expected from efforts to design machines to give a favorable performance for *long-line service.* A comparatively small improvement in the behavior of the machines will greatly better the performance of the system and largely eliminate the machines as a limitation.

I would like to say that I entirely agree with much that Mr. Silver says to the effect that in most actual situations, long transmissions without intermediate stations will not occur, but in this paper I have set myself this particular problem—I have considered the broad network in a second paper, presented at the Birmingham Convention entitled "New Type of High-Tenion Network." In this Birmingham paper I have made free use of high-tension switching.

With regard to high-tension switching, the essential thing in the layout of Fig. 5, is not the elimination of high-tension breakers so much as keeping the high-tension circuits electrically independent. Until some other means is shown of meeting high-tension short circuits without loss of synchronism, this high-tension separation stands as the most feasible proposal for a *heavily loaded isolated long line.*

Mr. Moreland, Mr. Booth and Mr. Bush have greatly emphasized what might be called the pendulum effect of the revolving parts of machines resulting from sudden changes in load. It is certainly true that the effects of such action must be considered. As these gentlemen do not tell by what method their curves are derived, no intelligent analysis of them can be made. If they are based on theoretically perfect pendulum action it is not likely that they represent the actual practical case on a large scale. If they take into account all the pertinent factors in the case, I do not see how they can have any general application, since these factors will vary greatly in different cases and are many of them subject to design.

They state that I have ignored such pendulum-action transients in my paper, but I would point out that this subject is treated on page 13 and in Fig. 6. It is true that it is not gone into at great length, but the system of my Fig. 5 is such as to largely eliminate any noticeable effect from this phenomenon.

I will close with calling attention to the fact that all the limitations of condensers, generators and pendulum action are of an exceedingly transient nature perhaps of the order of one or two seconds and that all that would be required to eliminate their effect is to speed up the automatic voltage regulator and exciter system to meet the actual speed of change in phase position of rotors, sufficiently so that machines do not have time to pull out of step. This is by no means a hopeless remedy. In this I assume that no sudden increases of load can occur in any big system able to cause more than a very moderate per cent increase of the load on any one generator, when divided pro rata over the system.

H. K. Sels: In regard to Mr. Goodwin's comments on our reference to the articles brought out in the *Electrical Journal* some time ago, our reference is not made to bring in the loss diagram in our present paper but merely the matter of general calculations of power diagrams. The two statements that he brings up were, first, the application of the mathematical solution for purposes of checking the power diagram and second, the "losses neglected" in the loss diagram. The point that we meant to bring out in the first statement was that analytical methods would only be applied when the scale on the power diagram came out, say, 5000 kw. in dealing with loads of 10,000 kw. In this case you would have to go to analytical methods to determine what you were doing. As none of the examples we have ever selected come in this class, we have never shown a parallel mathematical solution but considered the diagram sufficiently accurate. In regard to the loss diagram there are no losses neglected in the derivation of the loss formula or diagram. What we did have in mind when we said "the losses neglected when using the general circuit constants are practically constant," were the ordinary assumptions every transmission engineer makes for transformer exciting current, line leakage or corona losses. In other words one rarely includes these factors in a practical problem and furthermore being practically constant, "the most economical point of operating the line can be determined from the diagram" without including them.

Mr. Goodwin also refers to Equation 26 as being imaginary. He will see when he multiplies out the vector quantities, he gets another j term which makes a j^2 or -1, giving the m term a real value.

In regard to the remarks of Mr. Moreland, Mr. Booth and Mr. Bush on throwing sudden loads on lines producing heavy transient conditions, I wonder where that sudden load will come from. About the only way that you will get it would be to have one line drop out due to short circuit and the others assume that sudden load. It would never be obtained in the normal load curve of a system.

I want to agree heartily with Mr. Silver's remarks on high-tension switches. That is, these super-power systems are going to grow by connecting up nearby load centers, which may be done before you connect these to some outside power supply, so that you again come back to short sections. That means that sudden loads on long lines will not be obtained when these short sections drop out.

In regard to the statements of Mr. Moreland and Mr. Peek about getting increased power limits by raising the voltage, I want to point out that raising the voltage does not change the general shape of what we call the voltage power surface. When we use up the additional power that an increase in voltage gives us, we still have the problem of the general shape of this voltage power surface.

In regard to Mr. Worcester's remarks on the 25-cycle system with frequency changers as against the 60-cycle system, I might say that calculations made on 350-mile lines show them about equal, and I would suspect that his conclusions of slight reduction in cost would be correct for a 500-mile line.

H. K. Sels (Communicated after adjournment): In the discussion of the 750-mile line, Fig. 8 of our paper is sufficient proof that "the receiver must operate at lagging power factor." Mr Goodwin's statement that this is at variance with the 500-mile line is correct, but the comparison is wrong and no statement was made that the 500-mile line did not operate at leading power factor. A comparison of the independent diagrams for 500 miles shows them to be in entire accord with each other.

Mr. Terman raised the question of how the power diagram should be plotted. Apparently we are in agreement on this point

as the derivation of the power equation is on the basis that the following quantities represent lagging power factor.

$R + j\,x$ for impedance
$I_1 - j\,I_2$ " current
$P + j\,Q$ " power

which gives:

$$\frac{Q}{E} = - I_{-2}$$

Therefore, dividing the power equation by E_R^2 gives a current equation where lagging current is plotted lagging, yet lagging power is plotted leading.

Fundamentally, there is no basis for plotting power quantities and voltage and current quantities on the same diagram so that if mathematics rule the case, they should be plotted according to our analysis or if customary convention rules, lagging quantities should be plotted lagging. Our position at this time is to have everyone recognize this distinction so that the Standards Committee can define the plotting of power quantities according to the proper rule acceptable to everyone.

Considerable discussion has centered about the amount of power that can be transmitted 250 and 500 miles. All of this shows remarkable agreement in results and as Mr. Doherty points out in giving his figures, any differences are largely a matter of the conditions assumed. Some of these, I believe, are over-conservative and therefore some of the limitations are a matter of personal opinion. With all conditions considered, I am confident that given the problem to transmit 150,000 kw. per circuit 500 miles we will do it with equipment now commercially available if it is economical to do so at all.

Messrs. Hanker, Fortescue, Wagner, Evans, Bergvall and Shand (communicated after adjournment): The discussions which have been presented on these papers on "Power Transmission" have been very interesting and important. Due to the number and length of the discussions, it will not be possible to comment fully on the individual discussions. The papers were presented as a group, and a general reply will be made jointly by the several authors and supplemented by answers to questions raised on individual papers.

The discussions by Mr. Moreland, Mr. Booth and Dr. Bush will be considered first. Mr. Moreland, in connection with the Canadian power development, is concerned with the problem of determining the highest permissible loading of the transmission line under consideration. He apparently has confused this problem with the related one presented in the group of papers, namely, that of determining the maximum load that could be carried on a given transmission system with definite assumptions as to voltage, line and load characteristics. This attitude is particularly surprising to us in view of the visit to East Pittsburgh by one of his associates to secure information on stability, at which time we presented our methods of calculation and test data and pointed out that the maximum load was considerably in excess of the probable rating of a line. Furthermore, at that time we discussed the effects of electrical and mechanical transients of rotating machines and also we fully appreciated that the complete solution of the stability problem could not be obtained until all of these effects had been evaluated.

The maximum load on a transmission system must necessarily be obtained under steady state conditions, that is, by increasing the load in negligibly small increments. A definite method of solving this problem is presented in the group of papers. The complete solution to the problem of determining the highest permissible load of a transmission system from the standpoint of stability, was not given in the papers, because the problem is extremely complicated and the type of solution will vary with individual cases. The problem is complicated because the solution depends upon transients produced by changes in voltage, excitation, relative angular position of rotating parts, and governor and regulator characteristics. In the very nature of things, a simple solution cannot be obtained, and therefore, no attempt at this time was made to present a complete solution of the problem which Mr. Moreland infers was the object of the papers. The object was to present a general discussion supplemented by actual test data on stability because, in our opinion, the importance of transmission stability was not generally recognized.

The authors, however, did not avoid the problem of determing the permissible loading in view of the transient characteristics, but have indicated a method of calculation and submitted the results of tests. This method for analyzing transient conditions is based on the application of a suitably chosen static stability criterion. This static condition is determined by assuming:

(1) That the changes in the fields of synchronous machines produced by changed load or circuit conditions have been completed, and,

(2) That the machine excitations have not been changed. The static stability limit is easy to determine and has been proven both analytically and experimentally, as developed in the papers.

Mr. Moreland criticized the papers because static stability methods were employed to investigate transient stability, but he failed to read the papers to see how this static stability method was applied by the authors. To illustrate, Mr. Moreland submits a chart, Fig. 1, and implies that the methods given by the authors would indicate that for the conditions assumed, the load could be increased from 100,000 kw. to 190,000 kw., without loss of stability. The authors' method would have given the permissible increase as 38,000 kw. Mr. Booth and Dr. Bush in their discussion give the permissible load for this condition as being more than 40,000 kw., and less than 50,000 kw.

It appears, therefore, that the methods employed by Mr. Moreland and his associates and those employed by the authors give closely the same results, though their methods are based on "transient stability analysis," whereas the method employed by the authors is based on a static stability criterion. Consequently in analyzing Mr. Moreland's discussion, there can be found no support for his contention that the conclusions drawn by the authors are invalid, because of the methods employed to investigate the transient conditions.

Dr. Bush has presented a number of curves giving the results of computations of stability conditions for sudden increases in load. The method that takes into account accurately all the transients involved for changed load conditions (including prime mover governor, not mentioned by Dr. Bush) must necessarily be very complicated and require many assumptions. In the verbal discussion, Mr. Fortescue requested Dr. Bush to submit the basis for his calculations, which has not been given. Consequently, judgment of the value of Dr. Bush's method must be reserved until such time as adequate explanations are made.

It is perhaps desirable to point out some of the reasons why a static stability criterion should give good results for the transient conditions. This method in effect gives the limit toward which the analysis of the transient conditions must approach. Mr. Moreland apparently believes that the static stability method will fail because of the suddenness of changes introduced by switching operations. It is to be pointed out that part of the momentary demands are supplied by the reduction in kinetic energy of the load, condensers and generators at supply and receiver. Furthermore, for loads less than the static stability limit, there are many forces which tend to oppose the forces that would cause the system to pull apart. These forces include the kinetic energy of rotating masses, the transients in the exciter circuits, and the operation of regulators and exciters. During the transient condition, the flux in the main machines does not change instantly, and thus produces in effect an appreciable increase in the leading kv-a. available to hold the system in step. All these actions tend to prevent the instantaneous pulling out of step due to changed circuit or load conditions. It has been

observed on long distance transmission lines where instability occurs that the action of pulling out of step is a relatively slow process, requiring several seconds. The method of static stability analysis used by the authors therefore appears to have a reasonable basis, in assuming that flux in the main machines has been entirely changed in accordance with the new load or circuit conditions; and is pessimistic in assuming that the regulator and exciter systems have not had opporunity to act.

Mr. Booth's discussion on the intermediate synchronous condenser station is pertinent. In particular, he criticises the basis for considering the effectiveness of the intermediate condenser as presented in some of the papers, because the coincident variation in receiver and mid-point potentials is not considered. He feels that the assumptions made do not correspond with the usual operating condition. We do not understand that Mr. Booth questions the calculations submitted on the assumptions stated. Mr. Booth's point is pertinent, and if he had studied Mr. Shand's paper, he would have found that the particular point he raised was investigated at considerable length.

Mr. Booth's discussion leads to a conclusion with which the authors, however, must thoroughly disagree, namely, that the addition of an intermediate condenser station does not increase both the theoretical maximum output and the permissible output for various operating conditions. The calculations given in Mr. Shand's paper for the intermediate condenser stations show an important increase in the maximum load. The tests made in the shop prove very definitely that under favorable conditions, very large increases in the maximum load of a system can be obtained by the addition of an intermediate condenser station. In order to obtain stability, it is necessary, in general, to maintain the voltage adequately. In order to compensate for reduced voltage, the synchronous apparatus connected to the system should be of such design that a reduced voltage will cause an appreciable decrease in the lagging kv-a. or an appreciable increase in the leading kv-a. delivered. Mr. Booth's discussion, however, does bring out this fact that if the intermediate condenser station is of small capacity or high impedance, the increased output may not be important. This difficulty may be avoided by using synchronous condenser of larger capacity and of lower synchronous impedance.

The discussions by Messrs. Summerhayes, Doherty and Worcester and Miss Clarke are very interesting and important, particularly the discussion by Mr. Doherty. The importance of considering generator characteristics was recognized by the authors, but Mr. Doherty is justified in criticising the omission of calculations and data presenting figures on the effect of generator characteristics. His discussion was very clear and convincing, and in a sense rounds out the presentation of the subject by the authors.

The effect of generator characteristics, while important and at all times requiring consideration, is not nearly so great in limiting the power output as one might expect from the comparison of machine synchronous reactance with the reactance of the transmission line. This is due to the fact that the characteristics of the generator are considerably different from that of the line. With a decrease in voltage, a generator will supply an increased amount of reactive power, whereas a transmission line at reduced voltage requires an increased amount of reactive power due to both the increase of the $X\ I_2$ of the line for constant power, and to the decreased charging kv-a. Mr. Shand has carried out his calculations for the problem considered in this paper, and has found that the genertor characteristics limit the maximum output about 8 per cent. The tests given in the Evans and Bergvall paper show that the effect of generator characteristics for the particular system tested had a negligible effect in limiting the output because the test results checked very closely with calculations neglecting generator effects.

The simplified expressions for l, m, and n given in the discussion by Frederick E. Terman are similar to expressions used by one of the authors for some time. He has found them very convenient in studies involving the line alone. Mr. Terman also raises the question as to the correct manner of plotting leading and lagging kv-a. Following the analytical treatment given on page one of the paper by Fortescue and Wagner, one must logically arrive at the method of plotting employed. The basis for the equation:

$$P_s + j\,Q_s = \check{E}_s\,\hat{I}_s$$

is given in a paper by Mr. Foretscue on "The Measurement of Power in Polyphase Circuits" presented at the Midwinter Convention in 1923. By reference to this paper it can be seen that this method of plotting has a firm analytical basis.

We have read C. A. Nichol's discussion with a great deal of interest. The manner of including the effect of the generator in limiting the power is relatively simple when the constant value of synchronous reactance is used. In work which we have done subsequent to the writing of the papers we have found that it is not sufficiently accurate to use the so-called "synchronous reactance." We have preferred rather to use more accurate regulation charts for the generators and have evolved an approximate method of taking the generator characteristics into consideration, which are quite accurate.

The kinematic device for imitating the performance of long transmission lines which Professor V. Karapetoff is constructing at Cornell University, like his other devices, will undoubtedly prove to be highly instructive. While delighting in the use of mathematics, Professor Karapetoff derives still greater pleasure in demonstrating a phenomena in an entirely unmathematical manner. It would be highly entertaining to see a surge applied to one point of a line and observe its propagation along the line.

Mr. Longbottom has presented an interesting study of effect of the number of intermediate synchronous condenser stations on the performance of a transmission line. His figures show very clearly that under heavy load conditions the total exciting kv-a. required of all the synchronous machines is reduced when the number of condenser stations is increased.

E. B. Shand (Communicated after adjournment): In connection with the theory of transmission systems, there are one or two points I would like to amplify. First, in the paper by Messrs. Fortescue and Wagner, a mathematical analysis is given of the envelope of a certain family of power circles, while in the paper of Messrs. Evans and Sels, the same envelope is referred to as defining one type of power limit. The relation of this envelope to the system may be conceived in somewhat the following way.

When power is transmitted over a reactive circuit, such as a transmission line, the receiver voltage being controlled by varying the reactive current in the circuit, the ordinary relation is that a decrease of receiver voltage is accompanied by a decrease of reactive current (a leading current with respect to the line being considered positive). If the assumption be made that the load is independent of voltage, the power component of current must become greater at an increasing rate as the voltage is lowered, so that a point is eventually reached where the increasing reactive effect of the load current neutralizes the natural tendency for the magnetizing requirements to drop with voltage. For each value of constant power load there will be a value of receiver voltage at which the magnetizing requirements at the receiver end will be a minimum. Letting I_0 represent the magnetizing current at the receiving end, and Q the corresponding kv-a., two critical points may be expressed mathematically as follows:

$$\text{(a)} \quad \frac{S\ I_0}{S\ E_r} = 0 \text{ (For constant power)}$$

$$\text{(b)} \quad \frac{S\ (I_0 \times E_r)}{S\ E_r} = \frac{S\ \ Q}{S\ E_r} = 0 \text{ (For constant power)}$$

The envelope referred to is the locus of the condition represented by (b).

The above expressions represent the actual power limitations for two very special conditions of load and of regulating apparatus. Equation (b), represents the limit where the load has the characteristics of constant power, and zero or constant reactive kv-a. irrespective of voltage. The condenser would also have to deliver constant kv-a. irrespective of voltage. Equation (a) represents a similar condition, except that the reactive current characteristics are constant, rather than the reactive kv-a.

The assumption of a load of constant power and constant reactive kv-a. may often be approximated in actual practise, but the conditions for the regulating apparatus will differ considerably from this assumption. If a static condenser be considered, the reactive current will increase with the voltage, and the kv-a. with the square of the voltage. For a synchronous condenser, the current will increase with a drop in voltage, and within the operating range the reactive kv-a. will also increase as the voltage drops. With a load of the assumed characteristics and a synchronous condenser, the "envelope limit" would be slightly conservative.

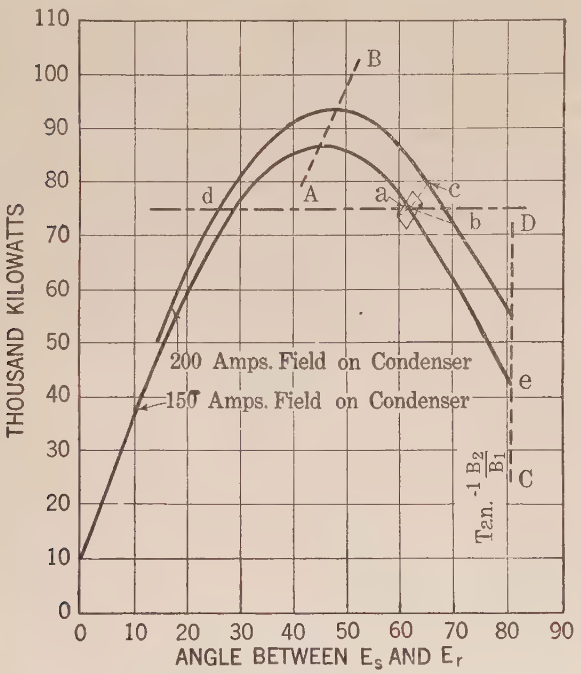

Fig. 55

When compound lines are considered, the reactive kv-a., required by the second section at the mid-point, may be expected to increase rapidly with a decrease of voltage and may more than neutralize the characteristics of the synchronous condenser. Therefore, the kv-a. available for the first section of the line may decrease with the voltage. This is illustrated by the 300-mile compound line, discussed in my paper. The "envelope limit" of this line is approximately 108,000 kw. From Fig. 11 of my paper the actual limit of output, with a size of condenser economically justified, would not be greater than 80,000 or 90,000 kw.

In the paper of Messrs. Evans and Bergvall it is mentioned that in making tests with a line purely of resistance, hunting was observable with practically normal excitation on the terminal condenser and without load on the line. The tendency to hunt, moreover, increased with the excitation. This is logical. A line without reactance becomes equivalent to a d-c. circuit and power can be transmitted only by a drop in voltage and not by a difference of phase angle. Therefore, by increasing the condenser excitation, the receiver voltage would approach the sending voltage, at which value it would be impossible to transmit any power except for the stabilizing effect of the condenser impedance. In this case the latter was comparatively small. These extreme line characteristics are not found in practise, although trouble is occasionally experienced on short high-resistance lines with over-excited synchronous motors at the end.

One further point in the paper of Messrs. Evans and Bergvall, will probably admit additional explanation. In referring to Fig. 5 of this paper the authors state: "If it were possible to get beyond the point of tangency between the two families of curves, an increase in synchronous-condenser excitation would actually decrease the receiver voltage," and further that the cumulative action of the regulator and reduction of voltage would eventually produce pull-out. According to the hypothesis made, *i. e.*, that the operation between the limiting lines $A\ B$ and $C\ D$ be stable, the above conclusions are perfectly correct, as may be deduced from the curves; the statement, however, without further analysis conflicts with the conclusions of my own paper regarding the condition of artificial stability, which, although not of great practical importance, is of interest on account of the principle involved.

Neglecting other phenomena which may be taking place concurrently, an increase in the field current of the condenser furnishes additional magnetization to the connected circuit and will increase its voltage. Also, an increase of field-current will increase the amount of power tending to flow over the line, rather than increase the tendency of the line to fall out of step. An exception to this latter statement will occur in a line of high relative resistance, that is, when the operating voltage is lower than the critical voltage $\frac{E_s}{2\ M\ B}$ This is very unusual.

These relations are probably more clearly seen in Fig. 55 in which the data of Figs. 4 and 5 of Messrs. Evans and Bergvall's paper, has been plotted on the basis of phase angles. The lines $A\ B$ and $C\ D$ correspond to similar lines in Fig. 5. The zone between these two lines represents the conditions under consideration.

Assuming a load of 75,000 kw. with a field excitation of 150 amperes, and at the point a the system will tend to drift out of step at e as is indicated by the slope of the curve of constant excitation. If the field is being increased so that its effect with respect to change of phase angle may be represented by the line $a\ b$, the power available will from that point be less than the requirement, and although pull-out will be retarded somewhat it will not be prevented. The voltage will also be higher than if the field had not been increased. If the rate of field increase were sufficiently rapid to be represented by the line $a\ c$, the power available would be greater than the load requirements and the masses would accelerate, stability finally being reached at the point d, which is on the stable slope of the curve.

From this discussion, it is apparent that the action of an automatic regulator in the zone considered will depend upon its resultant speed with respect to changes of angular displacement of the condenser rotor. With this being sufficiently great, the action of the regulator at the point a might be represented by the closed polygon about a, the rotor and the receiver voltage being kept in constant oscillation. This is the condition of artificial stability referred to in my paper.

STREET LIGHTING

A paper entitled "A survey of street lighting practise in the United States" has been prepared for presentation at the annual Convention of the Illuminating Engineering Society. This paper gives data on the cost of street lighting per capita and per mile, and the average levels of illumination in cities of different sizes.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

LOCAL LIGHTING APPLICATIONS*

Experiences of manufacturers have demonstrated that for the majority of industrial locations and other work places a general overhead lighting system is the most satisfactory. As a result, the majority of new industrial lighting installations are of the general overhead type, and gratifying increased production, more cheerful working conditions, improved morale, and decreased fire and accident hazard are being obtained.

There are a few types of work however, which require such high levels of illumination that a straight general lighting system would be uneconomical. In such places a combination of general and local lighting is needed. With a system of this kind, a medium level of general illumination which relieves contrasts, improves appearance, and makes for the general safety of the workers is supplemented by a high illumination at the work obtained from local lighting units.

Fig. 1—Sewing Room of Automobile Body Plant, Where 150 Foot-Candle Illumination is Provided at the Needle Point of Each Machine.

A typical example of this kind of lighting is seen in the sewing room, shown in Fig. 1. In sewing rooms the nature of the work is such that a high level of illumination must be provided at the needles on the machines. There must be a medium level of general illumination on the tables so that the operator may see to pick up and inspect the different pieces of material. Local lighting at the needle of approximately 40 foot-candles may be obtained from a 15-watt mill-type lamp fitted with a small aluminum finished steel reflector when installed on an adjustable arm. This level of local lighting has been found fairly satisfactory for sewing machine work.

The room shown in Fig. 1 is, however, used a greater part of the time for sewing black material for which the plant executives have found a higher illumination more desirable; they have accordingly provided approximately 150 foot-candles at the needle of each machine. This level of illumination is obtained by the use of a 60-watt lamp placed in a bowl steel reflector mounted on a flexible arm. This local lighting equipment is used to supplement a general overhead lighting system from which a fairly even distribution of illumination is obtained on the tables, benches, and shelves, with an average level in service of approximately 9 foot-candles. The general lighting equipment consists of 200-watt bowl-enameled gas-filled lamps in RLM Standard Dome reflectors installed on 12-foot centers and mounted 8 feet above the table tops. Under the local and general lighting systems in this room, accurate upholstering work can easily be done with dark as well as light goods. There are no disagreeable contrasts between the bright spot at the needle and the illumination throughout the room, and the operator's eyes are rested when looking away from the work into other parts of the room.

A modification of general overhead lighting which is rather closely allied with local lighting is obtained by placing a number of light sources with particular respect to one or more machines, benches, or the like where increased illumination or a preferred direction of light is required. This is called group or localized overhead lighting. Wherever the required amount of illumination can be economically obtained with a system of general lighting it is, of course, recommended. If, however, the economical limit is passed before the illumination obtained is high enough for the requirements of the work, a localized overhead system will often give entire satisfaction at a comparatively reasonable cost. The most common application of this type of lighting system is for lighting certain machines in industrial plants, textile mills, clothing establishments, etc.

A rather special use of the localized general lighting idea is for lighting the booths in which automobile bodies are painted. Fig. 2 shows one of these installations in use in the paint shop of the plant. In this operation the paint is sprayed upon the bodies by means of a flexible paint "gun" and must be applied evenly and in exactly the proper quantity. Painting is always an important operation in the manufacture of an automobile because the quality of the paint work and the finish obtained have a very decided bearing upon its marketability. Since a high level of illumination is required for this work, three RLM Standard Domes using 500-watt gas-filled lamps are installed in each paint booth. An average intensity of 40 foot-candles is obtained upon the car body. By mounting the units fairly low, but outside the workman's field of vision and directing them properly, a high illumination upon all the vertical surfaces as well as the tops of the bodies is obtained.

After the automobile bodies are painted they are

*From *Light*, Cleveland.

taken to the varnish room for their final finish. For this work the practise has been to provide 40 to 50 foot-candles by equipment installed in a manner similar to that in the paint shop. But even with this high illumination the painters found it impossible to inspect the surface of the varnish. An investigation brought out the fact that the workmen actually inspect the varnished vertical surfaces not so much by illumination which comes from above as by reflection in the varnish of some bright surface below the eye level. The reflections from the glassy varnish of this bright surface make it possible to detect flaws, scratches, or irregularities with ease.

In addition to a high level of illumination from overhead lighting units, angle steel reflectors are installed under the paint benches. The light from these reflectors is directed toward the floor paper which the finishers regularly used. This floor paper is changed frequently as the varnish dropped on it becomes thick. This automatically provides a clean reflecting surface of fairly high efficiency. It is recommended that the enameled steel angle reflectors be equipped with 200-watt blue glass bulb lamps, and installed under the paint bench on 18-inch centers, for a distance equal to the length of the auto body.

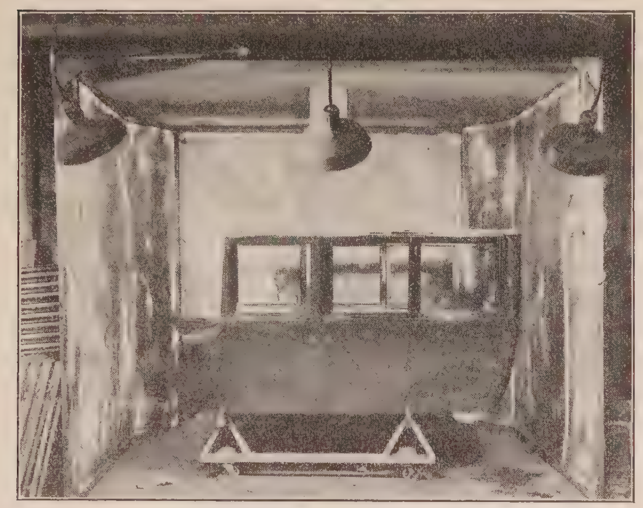

Fig. 2—Application of the Localized General Lighting Idea in One of the Paint Booths.

A general overhead lighting system for the varnish room should provide a high level of well diffused illumination. For this system blue glass bulb lamps of the 500-watt size should be used in units which highly diffuse the light, such as the Glassteel Diffuser. The outlets should be installed on approximately 10-foot centers and located 10 feet above the floor. With this general illumination and the special local lighting, the workman is able to inspect the newly varnished surfaces from almost any angle, and by means of the reflections he can detect every flaw in the surface he is varnishing.

It cannot be over-emphasized that any system of local lighting must be designed to supplement, and not to take the place of, a general lighting system; that the supplementary lamps should always be equipped with reflectors which adequately shield the eyes; and that the field for local lighting is limited to those operations where a high intensity of light is needed over a relatively small area, or where the light must be projected from some particular direction.

HOME LIGHTING EDUCATIONAL CAMPAIGN

The Lighting Educational Campaign, now in progress, is so broad in its scope that it well deserves to be ranked very high in its importance to the youth of the nation, for it is the largest educational campaign ever launched by any one industry in this country. The plans for the activity were formulated by the Lighting Educational Committee—organized especially for this purpose and consisting of representatives from the National societies which are, in any way, connected with the lighting industry. The activity has the enthusiastic endorsement of such organizations as the National Educational Association, the American Institute of Architects and the Eyesight Conservation Council of America, and holds the profound interest of many of our greatest educators and health promoters.

This campaign revolves about the Home Lighting Contest, now in operation among the 24,000,000 school children of High School age or less, who are attending the public, parochial and private schools of the country. The organization of this contest is such that the attention of the public is directed to the local activities inasmuch as the number and sizes of the prizes offered locally, are determined by the local committee. The best entries in the local contests will be submitted to the Lighting Educational Committee in competition for the National prizes.

Subordinated to the contest itself are numerous other ways in which the gospel of good lighting is placed in the limelight before the public. Among these are, magazine and newspaper advertising, and newspaper lessons, outdoor poster boards, window displays, lectures and the like. It is intended that the entire activity will be as purely educational and as free from the commercial aspect as possible. Nevertheless if this educational service is successfully rendered, and if the homes of the nation are thereby brought up to a conservative but healthful standard of lighting, there will be a potential market for lighting equipment in excess of a billion dollars to be added, and an annual central station revenue of a quarter of that sum. In view of this fact, the local committees which contain representatives from the central stations and lighting interests of those communities, can well afford to furnish their wholehearted support to the Better Home Lighting Activity.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

The Pasadena Convention

The plans and program of the Pacific Coast Convention at Pasadena were published in the September issue of the JOURNAL, and advance copies of nearly all of the papers have been widely distributed. Many of the members who signified their intention of attending the convention have left for the Coast and others are starting in a few days.

All reports which have come to us from the Committee in Pasadena indicate a most interesting and enthusiastic meeting.

Radio Developments to be Discussed at Philadelphia Section

A Paper on "Recent Developments in Radio Engineering" will be presented by J. H. Dellinger, Chief, Radio Laboratory, Bureau of Standards, Washington, D. C., at the Philadelphia Section meeting, scheduled for October 13th at the Engineers' Club, 1317 Spruce Street, Philadelphia.

The talk will cover extension of available frequency range, directive transmission, selective systems, precise frequency control, piezoelectric oscillators, beacons, direction finders, aircraft radio, radio vision, standardization of apparatus and frequency, methods of measurement, atmospherics, fading and interference.

Meeting of the Institute of Radio Engineers Postponed

The meeting of The Institute of Radio Engineers which was to be held Wednesday evening, October 1, 1924, at 8:15 o'clock, in the Engineering Societies Building, 29 West 39th Street, New York City, has been postponed until Tuesday evening, October 7, 1924.

American Engineering Council

MEETING OF ADMINISTRATIVE BOARD OCTOBER 17-18

A meeting of the Administrative Board of the American Engineering Council has been called for October 17 and 18 in Chicago. The Board will convene at the headquarters of the Western Society of Engineers, President James Hartness presiding.

American Gas Association Convention October 13-17

The Sixth Annual Convention of the American Gas Association will be held October 13-17 on the Steel Pier, Atlantic City, N. J.

Convention of American Electric Railway Association

The 43rd Annual Convention of the A. E. R. A. will be held at Atlantic City, N. J., October 6-10, and also an exhibit by manufacturer members. Several leading bankers and economists, will discuss the question of financing electric railways, and Mayor Magee of Pittsburgh; W. D. B. Ainey, Chairman of the Pennsylvania Public Service Commission; L. F. Eppich, past president of the National Association of Real Estate Boards, Denver; and other nationally known speakers will talk on the problems of the industry.

Fall Meeting of American Society of Civil Engineers

The St. Lawrence Deep Waterway to the Sea will be the major topic at the Fall Meeting of the American Society of Civil Engineers to be held in Detroit, Mich., October 22-25, 1924. Other subjects of special importance and interest to engineers familiar with hydroelectric development, city planning, sanitary engineering and highways will be discussed.

J. J. Hinman, professor of Sanitation Chemistry, University of Iowa, and F. W. Mohlman, Chemist of the Sanitary District of Chicago will speak at the opening session.

On October 23 Francis C. Shenehon will present his paper "The St. Lawrence Deep Waterway to the Sea" and many prominent engineers are expected to take part in the discussion.

Ice problems in hydroelectric plants will be the subject of the Power Division meeting the following day. Various addresses will be made by members of the Sanitary Engineering Division, the City Planning Division, and the Division of Highway Economics, U. S. Bureau of Public Roads.

Excursions to the Ford Motor Company plants, the Detroit Shipyards and water supply and sewage treatment plants will be made, as well as an inspection of the University of Michigan.

130th Meeting of Mining Engineers

The American Institute of Mining and Metallurgical Engineers will hold its 130th Meeting at Birmingham, Ala., October 13-15. The meeting will be preceded by a tour of inspection of the mining districts of West Virginia and Tennessee.

Future Section Meetings

New York Section: The first meeting of the New York Section will be held on the evening of Wednesday, October 15, 1924 in the Auditorium of the Engineering Societies Bldg., 33 West 39th St., New York, at 8.15 p. m. This meeting will be of a general nature addressed by several men very prominent in the

profession. Final details of the program have not as yet been definitely arranged but a notice giving full particulars will be mailed early in October.

Technical Activities of A. I. E. E.

In May, 1923 the President of the Institute was authorized by the Board of Directors to appoint a committee to review the organization of the committees in charge of technical activities, and to make recommendations regarding any revisions that might seem desirable of the Institute's machinery for handling technical matters of all kinds.

In accordance with the above action, a committee was appointed consisting of Past-presidents A. W. Berresford, Chairman, Dugald C. Jackson, Frank B. Jewett, Paul M. Lincoln, and William McClellan.

The committee held its first meeting in November, 1923, at which further consideration was given to material previously submitted by mail, embodying abstracts of reports of earlier committees appointed for a similar purpose, a digest of technical committee activities drawn from annual reports for the past seven years, and various suggestions that had been received or formulated by the members of the committee. A tentative report was submitted, after a second meeting, to the various technical committees of the Institute, with a request for criticism and suggestions. Later the various suggestions received from the technical committees, and from the Meetings and Papers Committee, were given consideration; and the complete report of the committee was submitted at the June, 1924 meeting of the Board of Directors. The report was approved with the understanding that certain phases would receive further consideration; and a supplementary report from the committee was submitted at the August, 1924 meeting of the Board of Directors, embodying a recommendation that the report be adopted as submitted in June. The Board approved the report as submitted and the committee was discharged with an expression of appreciation for the services rendered.

The report recommended certain changes in the designation of some of the technical committees, of which there shall hereafter be sixteen, as follows:

Committee on Electrical Machinery
Committee on Power Generation
Committee on Power Transmission and Distribution
Committee on General Power Applications
Committee on Applications to Marine Work
Committee on Applications to Mining Work
Committee on Applications to Iron and Steel Production
Committee on Electrochemistry and Electrometallurgy
Committee on Production and Application of Light
Committee on Communication
Committee on Transportation
Committee on Instruments and Measurements
Committee on Protective Devices
Committee on Electrophysics
Committee on Education
Committee on Research

The field of activity and the manner in which it is recommended that each of these committees shall function, were defined in the report, copies of which have been transmitted to the members of all Institute technical committees and others interested.

The following quotations from the report of the committee will be of interest:

"Study of technical committee activities indicates a degree of satisfactory performance which renders extremely problematical the desirability of any radical change. In reaching this conclusion your Committee agrees with each of the several committees previously appointed to consider this same subject. Moreover, such attempt as your Committee has made to analyze and to re-group on a basis seemingly more logical or more consistent throughout has made evident that complexity would result, rather than the hoped-for simplification. With the exception of certain general recommendations, therefore, your Committee has sought to fulfill its function by evolving more accurate definition of the fields of work of the various committees now existent and the expectable relation of the committee thereto.

"In general, technical committees are of two classes, namely, those in which electrical engineering considerations are dominant (instance—Committee on Transmission and Distribution) and those in which it plays a subordinate, if important, part or at the best assumes a position of equality (instances—Committee on Education, Committee on Iron & Steel Industry).

"From the former, there is expectable work of an initiatory nature of such scope as to cover the entire field and of a character to assure the general acceptance of the technical committee in charge as the leading influence in that field. From the latter, there is expectable work of a contact or correlating nature, varying in degree from largely initiative through joint activities to purely reportorial or statistical, dependent on the importance of the electrical engineering content in the given field.

"Your Committee agrees with previous committees in feeling that the Institute cannot, and, for its own advantage should not, expect to control permanently and generally those fields in which electrical engineering is not the dominant factor. The formation of specific organizations in such fields should be expected consonant with the interests involved and Institute contact should be arranged with such organizations by committees of the latter type dependent on the degree of electrical engineering content.

"Committees intermediate of the two general classifications may be thrown to one or the other by definition of the field to be covered. The definition, therefore, becomes the means of determining—first, the importance of the committee, and, second, the degree in which it meets its obligations. The accuracy of the conclusions will be no greater than the accuracy with which the definitions evaluate the practicable field.

"In attempting definition of the fields of work of the various technical committees, your Committee has no intention of limiting in any sense the scope of the work, but merely from its study of that work to express more definitely than has previously been attempted the division of the total field which has been evolved by the committees themselves over an extended period.

"The only innovation suggested is that of considering "requirements" as a specific division of each subject. For instance, the requirements for a generator may fall within the function of the Committee on Power Generation who are to operate it, and be specified by them to the Committee on Electrical Machinery who are to construct it, instead of lying wholly within the field of the latter. This procedure has seemed logical to your Committee, and has met with favor from the technical committees most concerned.

"*Standardization*:

In your Committee's opinion, a degree of standardization work by technical committees is not only permissible, but desirable. Composed, as it is, of individuals active and experienced in a given field and associated for the purpose of contact with the operations and possibilities of that field, the need for and the possibilities of standardization therein could first present themselves to the Technical Committee.

There are two steps in the making of a standard—

a. The perception of the possibilities, the evaluation of the desirability and the determination of the degree to which standardization may be practicable, including perliminary formulation.

b. The actual and final formulation of the standard.

Your Committee believes that "a" will best be accomplished by the Technical Committee and "b" under the auspices of the Standards Committee, the working committees of which, under these conditions, would instinctively be composed in large part of the men responsible for "a."

"*Reports*:

Your Committee cannot too highly commend the practise of reports by technical committees, whether of the annual type,

summarizing the year's performance, or the month to month type illustrated by "Illumination Notes" or the provision of papers for joint meetings, the latter being, in essence, reports on matters to which the Institute has definite though not dominant relation.

It recommends the placing of added emphasis on the importance to the Institute of this procedure and advocates calling to the attention of the committees, which are in essence contact or correlating in nature, the value of the service which may be rendered along these lines.

"*Sectional Organization*:

Your Committee joins with previous committees in feeling that sectional organization of technical committees is impracticable, at least at this time. While realizing the apparent advantage to the section of having in its membership a member of the Technical Committee in whose field lies an activity peculiar to, or prominent in, the territory of the section, it is felt that any attempt to arrange this comprehensively would so complicate the organization and operation of the Technical Committee as seriously to interfere with its accomplishment. It is believed that the coordination desirable can be secured through the Meetings and Papers Committee or in the exceptional instance where this is indicated the section may, of itself, appoint from its own membership a Sectional Technical Committee coordinating with and operating through the general committee."

Visiting Engineers from Abroad

During the month of September, several leading members of the engineering profession from abroad were in the United States, including Sir Charles L. Morgan, President, Institution of Civil Engineers; Wm. H. Patchell, President, Institution of Mechanical Engineers; Sir Charles A. Parsons, Honorary Member, Institution of Civil Engineers and of American Society of Mechanical Engineers and Senatore Gr. Uff. Luigi Luiggi, President, Italian Society of Engineers and Honorary Member of the American Society of Civil Engineers.

On Friday, September 26, the four National American Societies of Civil, Mining, Mechanical and Electrical Engineers gave a luncheon in honor of the visitors at the Engineers' Club, New York, which was attended by about one hundred officers and other prominent members of the American Societies.

The occasion afforded an opportunity for an informal exchange of courtesies which will tend to still further develop the cordial relations which exist between the various professional engineering societies of the different countries concerned.

French Exchange Professor in Engineering—1924

For the purpose of bring'ng about a closer relation of science and engineering between the United States and France, through the influence of personalities as well as the exchange of ideas, the engineering departments of the following seven universities, Columbia, Cornell, Harvard, Johns Hopkins, Massachusetts Institute of Technology, Pennsylvania and Yale, in cooperation with the Institute of International Education, arrange for an exchange of professors in Science and Engineering with the French Republic through the Minister of Education.

The Chairman of this committee of the seven universities is Dr. A. E. Kennelly, Past President of the American Institute of Electrical Engineers, and a member of the faculty of both Harvard and the Massachusetts Institute of Technology. The Secretary is Dean John Frazer, of the Scientific School of the University of Pennsylvania.

The professor who will go from the United States this year is Professor Emile Monnin Chamot of Cornell University, and he plans to leave for France the latter part of September.

Sixth Session of the International Commission on Illumination

GENEVA, SWITZERLAND—JULY 22-25, 1924

The sixth session of the International Commission on Illumination was held at Geneva, Switzerland, July 22-25, 1924. It was attended by delegates from the National Committees in the United States, Great Britain, France, Italy and Switzerland, and by a representative from Japan. This meeting was particularly notable as it marked the active entrance of the Commission into the field of practical problems of illumination. In addition to the plenary meeting, five technical sessions were held, devoted to consideration of the following subjects: primary standard of candlepower; definitions, symbols and vocabularies; measurement of lights of different colors; and wo sessions on practical use of artificial light. In all the sessions American contributions played a prominent part, notably the report by Dr. Herbert E. Ives covering an investigation on "A Primary Standard of Light following the Proposal of Wardner and Burgess." The meeting which dealt with definitions, etc., agreed upon a considerable number of terms and definitions to be added to those adopted at the 1921 session. The meeting dealing with heterochromatic photometry received reports from a special committee summarizing progress during the last three years from the national laboratories in England and France and from the Bureau of Standards Turning to the question of the actual use of light, the Commission heard three notable papers representing the situation in America with particular reference to the activities of organizations commercially interested in furthering its more efficient use. John W. Lieb set forth the point of view of the modern operator of central stations. His paper was followed by those of G. S. Merrill and A. L. Powell respectively on "The Demonstration Method of Teaching Good Lighting Practise" and "Practical Illuminating Engineering." Another group of papers dealt with street-lighting. The final technical meeting dealt with the legal regulation of lighting with reference to factories and school buildings. Automobile lighting was likewise discussed in a report from a special committee under chairmanship of Dr. Clayton H. Sharp.

At the closing plenary meeting the date of the next session was set for 1927 and it was unanimously voted to hold this meeting in America. The officers of the Commission reelected by acclamation are, as follows: Dr. Edward P. Hyde, President; Vice-Presidents, K. Edgecumbe of Gt. Britain, Guido Semenza of Italy and F. Rouland of France; Honorary Secretary and Treasurer, C. C. Paterson of Gt. Britain. The complete official report of proceedings is in preparation and will give the technical papers in the language in which they were presented with summaries of discussion in French. Copies of these proceedings will be available through the National Committee, Clayton H. Sharp, President; 80th St. & East End Ave., New York, N. Y.

NATIONAL RESEARCH COUNCIL

REINFORCEMENT OF CONCRETE PAVEMENTS

Announcement is made by Chas. M. Upham, Director of the Advisory Board on Highway Research of the National Research Council, that C. A. Hogentogler of the U. S. Bureau of Public Roads, has been granted leave of absence in order to conduct for that Board a fact-finding survey of the economic value of reinforcement in concrete pavements. This survey is to be national in scope, and will be conducted in cooperation with agencies interested in this important subject. It is proposed to cover the various soils, traffic and climatic conditions throughout the United States.

Mr. Hogentogler's experience in this work well qualifies him to undertake this investigation. He has been connected with the Pennsylvania State Highway Department and the Borough of

Columbia, Pennsylvania. For two years he was Assistant Professor of Civil Engineering at the University of Idaho and later engaged in research work for the U. S. Bureau of Standards and the U. S. Bureau of Public Roads. He is author of a number of papers on this subject which have appeared in various technical magazines.

ADVISORY BOARD ON HIGHWAY RESEARCH

Forty State Highway Commissions have already named representatives on the Advisory Board on Highway Research of the National Research Council. Through the State representation, the Highway Commissions and the Advisory Board will have a medium whereby research problems may be thoroughly studied. The problems will be brought to the attention of the various States and others engaged in highway research, and the solutions will be made known to the State Highway Commissions through their representatives, or contact men.

Announcement is made that the Annual Meeting of the Advisory Board will be held at the new National Research Council building, Washington, D. C., on December 4th and 5th, when the various committees will report and a program, to be announced later, will be presented. It is expected that there will be present at this meeting a representative from each State Highway Commission, as well as representatives of the member organizations of the Board and others interested in its work.

American Engineering Standards Committee

STANDARDIZATION NOTES

National Electrical Code Approved. The Regulations for Electric Wiring and Apparatus in Relation to Fire Hazard, of the National Fire Protection Association, generally known as the "National Electrical Code," 1923 edition, has been approved by the American Engineering Standards Committee.

Symbols for the Electrical Equipment of Buildings Approved. A list of 85 symbols for use in wiring diagrams for buildings has been approved by the American Engineering Standards Committee. The symbols are the work of a sectional committee under the joint sponsorship of the American Institute of Architects, the American Institute of Electrical Engineers, and the Association of Electragists, International.

The present standard is a revision and a considerable extension of the list first compiled by the National Electrical Contractors Association, in 1906. During the work, approximately 3000 symbols were submitted to the sectional committee. Mr. C. Kaiser and Mr. Farguson Johnson are chairman and secretary, respectively, of the sectional committee.

CODE OF LIGHTING SCHOOL BUILDINGS ADOPTED

With the approval of the Code of Lighting School Buildings as an American Standard by the American Engineering Standards Committee, a demand for definite, detailed and up-to-date specifications for lighting school buildings on the part of the architects of school buildings, school superintendents and school boards, and regulatory bodies has been met.

The present code is the result of a thorough revision of the code prepared and issued in 1918 by the Illuminating Engineering Society. A number of changes and improvements in lighting practise itself, since the 1918 code was issued, has made necessary its revision to conform with the best modern practise.

The new code differs chiefly from the old in being more specific. The illumination standards have been raised to conform with modern practise; specifications of definite requirements under the glare rule have been included; a limiting ratio of maximum intensity to minimum intensity in class rooms has been included in the rule relating to distribution of artificial light; reflection-factors have been specified in the rule relating to color and finish of interior; the rule relating to exit and emergency lighting has been amplified and a rule relating to the illumination of blackboards has been added.

The rules themselves are clear and concise, occupying less than four pages. They are followed by a non-technical discussion of the importance of compliance with them, and directions for carrying them out. These are accompanied by simple diagrams, illustrations of good and bad lighting, etc.

The present code was developed and adopted by unanimous action of a large and representative sectional committee made up of official representatives of the technical, educational, and industrial organizations concerned, acting under the leadership of the Illuminating Engineering Society, and the American Institute of Architects.

Two New Preliminary Reports on Standards Available

There is now available in mimeographed form a limited number of copies of reports on two of the proposed revised sections of the standards of the A. I. E. E. These two reports "Standards for Instrument Transformers" and "Standards for Electrical Measuring Instruments" are the results of the work of representative Working Committees Nos. 25 and 29, under the chairmanship of Mr. G. A. Sawin and it is proposed they come up for final consideration by the Standards Committee in December. The Standards Committee, in conformity with the plan for obtaining as wide cooperation as possible in the revision of the entire Standards, believes that these reports have reached the stage at which they should be offered for the criticism and suggestion of interested persons. Copies will be mailed on receipt of request by the Secretary of the Standards Committee, Institute headquarters. All replies containing suggestions, etc., should be mailed directly to G. A. Sawin, Supply Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. In order to permit of proper consideration these communications must be in the hands of Mr. Sawin by November 15, 1924.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute Headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—F. M. Bond, 621 W. Onondaga St., Syracuse, N. Y.
2.—H. E. Bradley, 1 Pine Crest Drive, Hastings-on-Hudson, N. Y.
3.—John D. Brown, Celite Products Co., Box 639, Lompoc, Calif.
4.—Harry S. Buchanan, 134 E. Ave., 54, Los Angeles, Calif.
5.—C. H. Gauss, 2319 E. Fayette St., Baltimore, Md.
6.—Frank W. Gross, 1135 W. 5th St., Santa Ana, Calif.
7.—Miguel Mesa Gutierrez, Bernardo Lopez 8, Jaen, Spain.
8.—T. J. Hodge, c/o Engg. Dept., Memphis Pr. & Lt. Co., Memphis, Tenn.
9.—W. T. Hutton, 6753 South Bishop St., Chicago, Ill.
10.—George Janssen, The Roxana Petroleum Corp., Arkansas City, Ark.
11.—Erle M. Jones, 370 Pape Ave., Toronto, Ont.
12.—E. R. McNee, 18 So. Seeley Ave., Chicago, Ill.

13.—Keith C. Millikin, Box 524, Midland, Ont., Can.
14.—Fred H. Nash, Box 366, Cushing, Okla.
15.—B. A. Ross, Phoenix Utility Co., Hazleton, Pa.
16.—Thomas F. Slattery, St. George Court, Stuyvesant & Wall Sts., St. George, Staten Island, N. Y.
17.—Kenneth H. Sloan, 11 Spruce Road, Inwood, L. I., N. Y.
18.—Max E. Sporn, 242 Penn St., Brooklyn, N. Y.
19.—George T. Tavenner, Kern House, 2nd Floor, 36-38 Kingsway, London, W. C. 2, England.
20.—J. L. Twining, Apt. 32, 703-9th Ave., Seattle, Wash.
21.—Adolph L. Ziegler, Westinghouse E. & M. Co., 160-7th St., Brooklyn, N. Y.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES (August 1-31, 1924)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ELECTO-DEPOSITION OF METALS. 9th edition.

By George Langbein; trans. with additions by William T. Brannt. N. Y., Henry Carey Baird & Co., Inc., 1924. 863 pp., illus., tables, 9 x 6 in., cloth. $7.50.

A new edition of this well-known handbook, made necessary by the exhaustion of the one published four years ago. Corrections and changes have been made wherever necessary.

ENGINEERING IN AMERICAN INDUSTRY.

By Conrad Newton Lauer. N. Y., McGraw-Hill Book Co., 1924. 94 pp., illus., maps, charts, 12 x 9 in., cloth. $2.50.

Mr. Lauer's rapid reconnaissance of the development of American industry since 1803 is particularly valuable for its numerous graphic charts. These are skillfully planned to show the industrial development of the country, decade by decade, the shifting of the centers of population and of manufactures, the relative rank of the leading industries, the production of the chief articles, the growth of railroads and other means of communication, etc. The illustrations, too, are excellent and illustrate forcibly the changes during the period.

THEORETISCHE TELEGRAPHIE.

By Franz Breisig. 2d edition. Braunschweig, Friedr. Vieweg u. Sohn, 1924. 548 pp., illus., diagrs., 9 x 6 in., paper. 26 M.

This volume belongs to a series covering the entire field of telegraphy and telephony. It provides a broad, thorough course in the theory of electricity, in which special attention is given to those questions which are most important to students of telegraphy. The author has attempted to reduce his mathematical discussions to the terms of ordinary algebra.

This edition has been thoroughly revised and partly rewritten.

THEORY AND PRACTISE OF PUBLIC UTILITY VALUATION.

By W. H. Maltbie. N. Y., McGraw-Hill Book Co., 1924. 201 pp., 8 x 6 in., cloth. $2.00.

A discussion of the principal points in the theory and practise of the valuation of public utilities. The book is not intended for specialists but for the general public and is written in a way which will be intelligible to the latter.

DIE WISSENSCHAFTLICHEN GRUNDLAGEN DER NASSEN ERZAUFBEREITUNG.

By Josef Finkey. Berlin, Julius Springer, 1924. 288 pp., diagrs., tables, 9 x 6 in., paper. $2.40.

In most treatises on ore dressing the emphasis is placed on descriptions of apparatus and machinery, while the physical principles underlying the processes are given scanty attention. Rittinger's well-known treatise is an exception, but it is over fifty years' old, and the technique of ore dressing has made great progress during this period.

The present work discusses the theory of wet processes, in the light of the literature and of investigations by the author. Chapters are devoted to the mechanical principles of wet ore dressing, to preparatory processes, jigging, and concentrating. The book is intended to assist in the selection of suitable equipment, to give an understanding of the processes which will lead to economical, efficient operation, and also as an aid to designers.

RELATIVITY AND GRAVITATION.

By T. Percy Nunn. Lond., University of London Press, 1923. 162 pp., 8 x 5 in., cloth. $2.40. (Gift through E. P. Dutton, N. Y.)

Most books upon this theory are either popular expositions intended for readers with no mathematics, or else serious treatises presupporting considerable technical training. This publication occupies a middle ground. It is intended for the layman with the usual college training in mathematics, but the demonstrations are given with unusual fullness and the use of the tensor calculus is avoided.

RAILWAY RATES AND COST OF SERVICE.

By Owen Ely. Boston & N. Y., Houghton Mifflin Company, 1924. (Hart, Schaffner & Marx prize essays). 148 pp., 8 x 5 in., cloth. $2.00.

A study of this important problem from the economic point of view. The author examines the work and policies of the Interstate Commerce Commission and recent date regulation. He then analyzes the rate theories advanced by students of transportation, following this by a study of the relation between operating costs and rates, and an examination of the attempts to develop a technique of cost accounting. He then draws conclusions as to the efficiency of the present rate system, socially and economically, and as to the proper program of rate reconstruction.

LINEAR INTEGRAL EQUATIONS.

By William Vernon Lovitt. N. Y., McGraw-Hill Book Co., 1924. 253 pp., 8 x 6 in., cloth. $3.00.

Presents in a readable, systematic manner the general theory of linear integral equations, with some of its applications to

differential equations, the calculus of variations and some problems in mathematical physics. These include problems in vibration and in the flow of heat in a bar.

FUEL OILS AND THEIR APPLICATIONS.

By H. V. Mitchell. Lond. & N. Y., Isaac Pitman & Sons, 1924. 171 pp., illus., tables, 7 x 5 in., cloth. 5s.

The uses range from steam raising and the heating of metallurgical furnaces to the production of power by internal combustion engines and include stationary and traction service on land and the use of oil fuel at sea. Typical burners and oil-burning installations are described. The book will be useful as a clear, concise introduction to the subject and as a text for those who are concerned only with the basic technology of it.

FUEL ECONOMY IN STEAM PLANTS.

By Arthur Grounds. London & N. Y., Isaac Pitman & Sons, 1924. 106 pp., illus., diagrs., tables, 7 x 5 in., cloth. 5s.

Discusses the losses that result from neglect of the process of burning coal and generating steam, showing how these losses may be obviated or reduced.

ANALYTICAL MECHANICS.

By Edwin H. Barton. 2d edition, rev. & enl. London & N. Y., Longmans, Green & Co., 1924. 593 pp., diagrs., tables, 9 x 6 in., cloth. $6.20.

A reasonably complete text-book on theoretical mechanics, intended for those possessing an elementary knowledge of the calculus. Includes the kinetics and statics of solids and of fluids, mechanisms and strains and elasticity. Covers the work required by degree candidates in British universities.

This edition has been carefully revised and many new examples added.

TEXTBOOK OF CELLULOSE CHEMISTRY.

By Emil Heuser; translated from the 2nd German edition by C. J. West and G. J. Esselen. N. Y., McGraw-Hill Book Co., 1924. 212 pp., diagrs., tables, 8 x 5 in., cloth. $2.50.

Professor Heuser's book is intended to present a brief critical discussion of results of investigations of the properties of cellulose and to evaluate these results with reference to the problem of its constitution. It is a convenient summary of theoretical considerations from a logical viewpoint, which will be useful to students of organic chemistry and the chemistry of paper, textiles, etc., who need a consistent, even though fragmentary view of cellulose.

The original German work appeared in 1920. The translation is from the edition of 1922.

SCALES AND WEIGHING, THEIR INDUSTRIAL APPLICATIONS.

By Herbert T. Wade. N. Y., Ronald Press Co., 1924. 473 pp., illus., diagrs., 9 x 6 in., cloth. $6.00.

This book describes the various types of weighing machines which are available for industrial use and their advantages and limitations, and gives examples of their use in various industries and for special purposes. It is intended as a guide in the selection, use and maintenance of scales, and is a welcome addition to the short list of books on the subject. A bibliography is included.

CHEMISTRY OF RUBBER.

By D. W. Luff. Lond., Ernest Benn, 1923. 232 pp., illus., tables, 10 x 7 in., cloth. 25s.

Discusses the chemical principles involved in the cultivation, collection and manufacture of rubber, and gives consideration to the concomitant changes in physical properties which occur during vulcanization. The author is research chemist to the north British Rubber Company.

PERSONAL MENTION

ROBERT E. RYAN has accepted a position with Dwight P. Robinson & Co., Pittsburgh, Pa.

H. P. TRAWICK has accepted a position in the Switchboard Sales Department of the General Electric Company, Baltimore, Md.

EDWARD CLINTON FREISEN has joined the forces of the Dwight P. Robinson Company, Pittsburgh, Pa., as Line Construction Engineer.

H. F. WINTE has been placed in charge of the Western District Office of the Sessions Engineering Company, Northwestern Bank Building, Portland, Oregon.

JOHN B. BALTZER, is now instructor for the David Rankin, Jr. School of Mechanical Trades, St. Louis, Mo., having left the United Railways Co. of St. Louis.

MARTIN J. INSULL, Vice-President of the Middle West Utilities Company, Indianapolis, Indiana, has been elected President by the Board of Directors.

GEO. S. MILNER is now President of The George S. Milner Co., 410 The Arcade, Cleveland, Ohio. He was formerly connected with The Erner Electric Company of that city.

J. R. ROITBURD has left the employ of the New York Edison Co. and is in the Electrical Designing Department of Gibbs & Hill, located at Pennsylvania Station, New York City.

FRED. W. PETERSON is at present employed as Electrician for the Brooklyn Edison Co., Brooklyn, N. Y. He was formerly Electrical Inspector with the Public Service Production Co.

C. O. SCHOOLEY is now Assistant Engineer, Standard Underground Cable Company, Perth Amboy, N. J. He was formerly Resident Engineer, Westinghouse Electric & Mfg. Co., Lester, Pa.

OLIVER S. LYFORD is now Vice-President and General Manager of the Lawrence Investing Company, 77 Kraft Avenue, Bronxville, N. Y. Mr. Lyford's New York office has been discontinued.

A. R. NAHRGANG has severed his connections with the Western Electric Co. of Chicago and has become associated with the New England Telephone and Telegraph Co., 50 Oliver St., Boston, Mass.

GEO. A. MILLS is Vice President and General Manager in charge of the Kewanee Public Service Company, Kewanee, Ill., having left the Wisconsin-Minnesota Light and Power Co., Eau Claire, Wis.

ELGIN B. ROBERTSON, formerly electrical engineer for the Railway & Industrial Engineering Co. of Greensburg, Pa., is now manager of this company's Chicago office, 602 Monadnock Bldg., Chicago, Ill.

HAROLD B. BLACK will be an instructor of electricity in the Boys' Vocational School, South Bend, Ind. For the past three years he has served in a similar capacity at the Harrisburg Mechanical School.

JOHN B. SUTTOR, JR., is now a Member of The Legislative Council of New South Wales, Sydney, Australia. Mr. Suttor is therefore no longer connected with the Australian General Electric Co. of Sydney.

CARLTON E. BUTLER has changed his business connections from the Westinghouse Electric & Mfg. Co., Chicago, Ill. to that of Radio Editor, Chicago *Evening American*, 324 W. Madison St., Chicago, Ill.

I. V. LE BOW has resigned his position as Head Electrical Engineer with the Terrell Croft Engineering Co., St. Louis, Mo., to accept a position in the Engineering Department of the California-Oregon Power Co., Medford, Oregon.

DAVID E. DRAKE, dean of the Sales Department of the Westinghouse Electric & Manufacturing Company, over 50 years in the electrical industry and 34 years with this company, retired recently. He will make his future home at San Diego, Cal.

ROBERT G. TUGENDHAT has resigned his position as Electrical Research Engineer with the Baker Perkins Mfg. Co., Saginaw, Mich., and left for Europe the latter part of August to make a business visit. He expects to return to the United States next February.

W. HOLLIS HOFFMAN has resigned from the Bureau of Engineering, Navy Dept., Washington, D. C., where he had been designing radio transmitting apparatus, to become connected with The C. F. Burgess Laboratories, 1011 E. Washington Ave., Madison, Wis.

ARCHIBALD J. G. RUSSELL has taken over the sales management of The National Electrical and Engineering Co., High Street, Christchurch, N. Z., agents for the American General

Electric Co. He was formerly Sales Engineer, Jas. J. Niven & Co., Ltd., of that city.

J. H. Tadlock has resigned his position as Designing Engineer in the alternating current department of the General Electric Co., Schenectady, N. Y., and is at present assistant to the resident engineer on Stone and Webster's Baker River project at Concrete, Washington.

H. P. Mathieu has resigned from The American Bridge Company and with R. L. Morgan, recently of Tulsa, Okla., has opened a plumbing and electrical contracting firm under the name of Morgan and Mathieu Plumbing and Electrical Company, located at 1318 Willard Avenue, Houston, Texas.

Hawley O. Taylor, recently head of the Electrical Department of Franklin Union, Boston, and formerly Consulting Physicist, Bureau of Standards, Washington, D. C., has been appointed head of the Physics Department and supervising head of Mathematics and Chemistry at John Brown University, Sulphur Springs, Ark.

M. F. Clement has become manager of the Orange County Public Service Co., Inc., Middletown, N. Y. He was formerly electrical engineer with Chas. H. Tenney & Co., Boston, Mass.

T. H. Dillon has left the Massachusetts Institute of Technology, Cambridge, Mass., and is now Professor of Public Utility Management, Harvard Graduate School of Business Administration, Harvard University.

Professor G. W. Osborn Howe, of Glasgow University, was a caller at Institute headquarters, New York, September 13. Professor Howe, who was president of the Engineering Section at the meeting of the British Association for the Advancement of Science held in Toronto, August 6-13, made brief visits to various places in the United States prior to sailing for home on September 20.

Oscar S. Tyson and L. W. Seeligsberg have incorporated O. S. Tyson and Company, Inc., to conduct an advertising agency with offices in the Hudson Terminal Buildings, 50 Church Street, New York. Mr. Tyson, President of this organization, recently resigned as Vice-President of the Rickard and Company advertising agency. He was formerly Eastern Sales Manager of *Electrical World* and Eastern Advertising Manager of *Factory Magazine*.

Farley Osgood, president of the American Institute of Electrical Engineers, has resigned as vice-president of the Public Service Electric and Gas Company of N. J. in charge of electrical operation. Announcement of the resignation and its acceptance "with deep regret" was made by Thomas N. McCarter, president of the Public Service Company, who said: "After leaving the service of the company Mr. Osgood plans to take a well-earned vacation. He will visit California in connection with his duties as president of the American Institute of Electrical Engineers. On his return he will undertake certain engineering work of the highest importance to several large electrical companies, of which the Public Service is one."

Obituary

John Mayhew Elwell, an Associate of the Institute, died after an illness of one day on August 28th at the Jefferson Hospital, Philadelphia. Mr. Mayhew had been connected with the Philadelphia Electric Co. since 1907 and was at his office when stricken.

Lawrence Birks, Chief Electrical Engineer, Hydroelectric Branch, Public Works Dept., Wellington, New Zealand, passed away during the summer. Mr. Birks has been acting as Local Honorary Secretary of the A. I. E. E. for New Zealand since February, 1922. He joined the Institute as an Associate in 1911 and was transferred to Member in 1913. Mr. Birks was born in Adelaide, Australia on May 19, 1874. He graduated from Prince Alfred College, Adelaide 1891, University of Adelaide 1894, University College, London 1896. He then served as Asst. Prof. of Engineering at the Heriot Watt College, Edinburgh, Scotland, 1896-97. From 1900-03 he was Asst. Electrical Engineer of the Sydney, N. S. W. electric tramways, in 1904 City Electrical Engineer of Christchurch, N. Z. In 1906 Mr. Birks entered the employ of the New Zealand government as engineer and in 1911 was appointed Asst. Elec. Engineer in charge of development of water power throughout the dominion, in which branch of government service he remained, finally becoming Chief Electrical Engineer in 1919.

Oscar Duane Smalley, Instructor of Electrical Engineering, Iowa State College, Ames, Iowa, died on September 8th. Prof. Smalley received his B. S. and M. S. degrees in electrical engineering from the University of Nebraska, and during the war was connected with the Air Service in France. Since his return he has held positions with the American Electric Co., St. Joseph, Mo., and with V. L. Hollister, Lincoln, Nebraska, later joining the faculty of Iowa State College.

The Latest Ideas in Illumination

The first meeting of the New York Electrical Society for the administrative year 1924-25 promises to be unusually interesting. The Director of the Lighting Research Laboratory, National Lamp Works, Cleveland, Mr. Luckiesh, will explain some of the very latest ideas that have been developed in the illuminating field. He will show among other things how artificial lighting has not kept pace with its rapidly decreasing cost and the increasing standards of living, prove daylighting indoors costs as much as artificial lighting and is less satisfactory and will discuss the quality of light with relation to the human being from several viewpoints. In connection with new data on the effect of quantity of light on our ability to see he intends to show that the most effective intensities are many times those with which we are ordinarily familiar in artificial lighting. Mr. Luckiesh will accompany his talks by interesting demonstrations and will test the speed of vision of the audience. This is believed to be the first time such a test has been attempted. Engineers interested are cordially invited to attend. The meeting will be held in the Auditorium, Engineering Societies Bldg., 33 West 39th St., New York at 8 p. m. on Thursday, October 23, 1924.

Engineering Societies Employment Service

The results of the past fiscal year just closed, of the Engineering Societies Employment Service are most encouraging. It has been the aim of the National Societies to improve and extend the service and also to make it self-supporting, and that ambition is now beginning to be realized.

The contributions from men placed have gradually increased each month, reaching a total of a little over $6000 for the past year. Subscriptions to the Employment Bulletin have also increased, bringing in a revenue of some $16,000. These two amounts, together with the amount appropriated by the four National Engineering Societies, give the Bureau an income of $30,000. Nearly a thousand men were placed during the year.

The total expenditures for the year were approximately at the rate of $22,000, leaving a balance of some $8000. It is planned now to engage an assistant with qualifications especially fitted for this service and to utilize a part of this money as a beginning of a working capital for both the improvement and the expansion of the employment service, which has so long been the program of the National Societies. The majority of men placed are now in turn contributing to the support of the bureau, and it is hoped to establish branch offices of the service in several of the large cities so as to be of benefit not only to a greater number, but to a greater extent in other districts and make the service more definitely national in scope.

The Directors, consisting of the Secretaries of the Four National Societies of Civil, Mining, Mechanical and Electrical Engineers, are now at work upon the organization of branch offices.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will, it is hoped, be sufficient, not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

SALES ENGINEER, electrical illuminating, 22-40, experienced in industrial residential, or commercial lighting, or those who are qualified to enter this phase of the public utility field. Apply by letter giving age, education, experience, and salary desired. Location, East. R-4631.

RELAY ENGINEER, familiar with Westinghouse relays and modern methods of improving continuity of power service. Must be man with initiative and keen sense for investigating interruptions to service. Salary $225 a month to start. Location, Middlewest. R-4655.

ELECTRICAL ENGINEER, experienced in making time studies in underground distribution work. Salary $275 a month. Location, New York City. R-4725.

SALES REPRESENTATIVE, calling on engineers of power, lighting, railway and industial plants, renewal products, Location, any territory. R-4739.

SALES REPRESENTATIVE, calling on industrial plant engineers, renewal products. Location, New York City. R-4740.

MEN AVAILABLE

GRADUATE ELECTRICAL ENGINEER with two years' telephone experience and three years' teaching experience, desires position in Middlewest or Western United States. Available on thirty days' notice. B-7629.

GRADUATE ELECTRICAL ENGINEER, age 32, married, twelve years' experience design, installation, operation of industrial plants. Also export sales engineer having represented in Europe manufacturer of high tension insulators and electrification supplies. Has executive ability and good business judgment. Knows German, French, Italian, etc. Now available. B-8564.

ELECTRICAL GRADUATE with five years practise in designing power plants, distributing systems and sub-stations. At present employed, wishes to change position. Available at two weeks' notice. B-8456.

RECENT GRADUATE, B. S. in E. E., age 23, student A. I. E. E., desires start in electrical engineering. Experience, (summer positions) shop practise in several large manufacturing plants. B-8572.

TECHNICAL GRADUATE IN E. E., with inventive ability, desires position as research or experimental engineer on electrical-mechanical patent development work. Qualified to develop original ideas into marketable working models. Good knowledge of patent office proceedings. Twenty years electrical experience. B-6718.

ELECTRICAL AND MECHANICAL ENGINEER, graduate with broad collegiate education, age 38. Desirous of making a change for a position of responsibility. Sixteen years' experience in shop, drafting room and engineering department with electrical manufacturers and contracting engineers. For last nine years in charge of electrical department of large contracting engineering company. B-8585.

ELECTRICAL ENGINEER, technical graduate, age 34. Ten years' experience in design, construction and sale of induction motors, A. C. commutator motors, alternators, transformers, etc., with leading European and American manufacturers. At present employed but desires a position of greater responsibility and opportunity. Pacific States preferred. B-8592.

ELECTRICAL AND MECHANICAL ENGINEER with technical education. Twelve years' experience in design, construction and operation of large hydro-electric plants and high tension transmission. Lately operating engineer, district superintendent and district manager of large public utilities company in Central America. Age 34, married. Location preferred, Central or South America. Languages, English, French, Spanish. B-8593.

ELECTRICAL ENGINEER, technical graduate, two years' experience in charge of electrical installation and maintenance and mechanical and electrical tests in an industrial plant. Student of Alexander Hamilton course. Desires construction or manufacturing work along electrical lines. Vicinity of New York preferred. B-6829.

B. S. IN E. E. 1922, age 26, single. Two years instructing in E. E. department of state university and summer work on G. E. test. Public utilities work in West or on Pacific Coast preferred. Minimum salary $2000 per year. B-8559.

HYDRO-ELECTRIC ENGINEER wishes position as superintendent or manager for public utility in town of 5000-10,000. Twelve years practical experience in the design, construction and operation of hydro-electric plants. Protestant, age 31, married. Wish position where conscientious application will be appreciated. Best of references. At present employed. Minimum salary $3000. Available short notice. B-8601.

ELECTRICAL ENGINEERING GRADUATE, four years out of college, having had experience in testing, switchboard engineering, designing and distribution, desires position other than drafting. B-8622.

ELECTRICAL ENGINEER, recent graduate (1924). Desires connection with public utility, public service or manufacturing company where engineering experience can be acquired. Willing to start low. Experience main object. Previously employed during summer months by large public service company. Single. Desires to locate in New York City or vicinity. B-8606.

1921 GRADUATE ELECTRICAL ENGINEER desires position with light and power company or consulting engineer. Experience in layout and construction of power plants, substations, and switchboards. Also experience in operation of hydro-electric power plants. At present employed in power analysis with large electrical concern. Location preferably East or Middlewest. B-8634.

YOUNG MAN, electrical engineer interested in physics wishes to enter the service of an organization offering promise of a career. Is 26 years old, has E. E. degree and has done post graduate work in physics. At present employed but would like to start in testing or similar work with a view towards development or research. Salary no object. Will locate anywhere. B-3411.

SALES ENGINEER, graduate electrical engineer with experience in motor and control sales in the middle West and East, also some radio sales. At present employed but desires wider field and will consider a position offering possibilities in any part of the United States. Age 27. B-8633.

ENERGETIC YOUNG MAN, 31, sixteen years of electrical experience of various kinds, as apprentice, mechanic, engineering assistant and supervisor. Desires to connect with a firm that provides equal opportunities for the college graduate and self educated practical man. Have been in present employment since 1912; was chief electrician in Navy during war. Speak, write and read English, German and Bohemian. Will consider employment outside of U. S. Present salary $2700. B-8502.

ELECTRICAL GRADUATE, 28, married. Three years electrical testing and supervising in machine switching telephone exchanges. Employed at present but desires position offering better opportunities for advancement and for using technical knowledge. Testing or laboratory work preferred; location, New York City. B-8603.

ENGINEER EXECUTIVE, desires new connections. Extensive experience as executive in charge of design, research and production engineering both on limited and quantity production involving special electrical and mechanical design features. Sales experience in handling both domestic and foreign negotiations. Electrical engineering graduate 1912, age

37, married. Available thirty days' notice. B-8692.

ELECTRICAL ENGINEER, desires position as superintendent or manager of electrical utility property in city of 5000 to 10,000 population. Experience covers four years as superintendent of several southern cities, three years as assistant distribution engineer in one of the growing cities of Texas caused by oil booms. Preference as to location, North Central States. B-8319.

GRADUATE ELECTRICAL ENGINEER with eight years' experience in the engineering of distribution and transmission lines, power house and substations, desires a similar position involving responsibility and chance for advancement with a progressive utility. Excellent references. Available on reasonable notice. B-7585.

FACTORY EXECUTIVE, electrical engineer, M. I. T. '13, age 34. Five years with General Electric Company, one year as engineer officer in U. S. Army, three years in France as electrical engineer in manufacturing plants. Two years in Italy as manager of large lamp works and wire drawing plant. Knowledge of French and Italian. B-8651.

TECHNICAL GRADUATE, age 25, with two years' experience in plant engineering and development work, desires connection with reliable firm with view to advancement. Married, location immaterial. Available immediately. B-8650.

ELECTRICAL DRAFTSMAN, desires position to handle power house lighting installation. At present employed by construction engineering concern. B-7666.

ELECTRICAL AND VALUATION ENGINEER, technical graduate, New York State license, 32, married. Ten years' experience public utility, engineering and construction. Valuation and rate engineer for large utility at present; familiar with classification of accounts and would welcome chance to start such a department in some utility. B-8488.

RECENT GRADUATE, B. S. in E. E. 1924, age 22. Desires position in an industrial plant or a public utility as a student engineer. Would also consider a position in sales work. Location preferred, Eastern States, but will consider Middlewest. B-8699.

GRADUATE ELECTRICAL ENGINEER 1921, age 25, single, desires position with a concern in operating or engineering departments. Have had two years' experience in supervising design, maintenance and operation of machine switching telephone equipment. Prefer location in Eastern U. S. Available on short notice. B-8699.

TECHNICAL GRADUATE, four years, experience with a large public utility in the design of transmission and distribution power lines. Thoroughly experienced in estimating, and construction of aerial and underground lines. Capable of interviewing mill owners and consumers of large blocks of power. Would like to connect with private concern, (although not essential), either at home or abroad. Slight knowledge of Spanish. B-8707.

YOUNG ELECTRICAL ENGINEER, graduate '23, age 22, with power plant construction and commercial small motor installation experience, would appreciate an opportunity to connect with a reliable manufacturing concern in either the engineering or sales departments. Available on fifteen days' notice. B-8641.

WORKS ENGINEER, MAINTENANCE ENGINEER, fifteen years' experience, installation and maintenance of mechanical and electrical equipment in large industrial plants. Construction and operation of power plants. Building construction and repairs. Age 35, married. Now available, salary $3600. R-2696.

Past Section and Branch Meetings

SECTION MEETINGS

Cincinnati

Fault Finding on Transmission Cables, by S. Aronoff. The paper was illustrated with slides. September 11. Attendance 43.

Los Angeles

Modern Ideas of Stars, by Dr. John A. Anderson, Mount Wilson Solar Observatory. The talk was illustrated by slides. June 23. Attendance 51.

Mexico City

Business Meeting. June 5. Attendance 18.

Mr. Larralde, who was the Section delegate to the Annual Convention, gave a talk on the papers read at the Convention. The following officers were elected: Chairman, D. K. Lewis; Secretary-Treasurer, E. F. Lopez; Vice-Secretary-Treasurer, C. M. Carrillo; Executive Committee, Messrs. Carlos Macias, Bourlon, Boynton, Solis Payan, and Muller. August 7. Attendance 37.

Syracuse

Electrical Engineering in Retrospect, by Paul M. Lincoln, Cornell University. December 17, 1923.

Relation of Investment to Cost of Electric Service in the Community, by S. B. Storer, Technology Club of Syracuse. January 28.

Light and Production, by R. W. Shenton. February 18.

The Trackless Trolley, by J. W. Collins, Rochester Railway Commission. April 7.

The Atmosphere as a Factor in Electrical Engineering, by Past-President Harris J. Ryan. May 21.

Schenectady

Annual Meeting. Special entertainment was provided and refreshments were served. May 28. Attendance 125.

Theory of Relativity in Graphical Representation, by Professor Vladimir Karapetoff. July 23. Attendance 150.

Vancouver

Stave Falls Power Developments, by J. I. Newell and A. F. Tredcroft. An excursion to Stave Falls was also made, where the members were entertained at luncheon by the B. C. Electric Rwy. Co. August 30. Attendance 49.

BRANCH MEETINGS

University of Arizona

Business Meeting. The following officers were elected: President, Edward Moyle; Vice-President, Mr. Scarlott; Secretary, James Wilson. May 23. Attendance 20.

University of California

The Meaning and Purpose of Defense Day, by Mr. Gerlach, student.

The Muscle Shoals Project, by Mr. Cowles, Pacific Gas & Electric Co. August 27. Attendance 60.

University of Florida

The meeting was devoted to general discussion. April 14. Attendance 15.

University of Nevada

Business Meeting. The following officers were elected: President, Charles Hicks; Secretary and Treasurer, George Fairbrother. May 7. Attendance 25.

Virginia Military Institute

Development of the Mercury Turbine, by J. B. Taylor, Charlottesville, Va. The following officers were elected: Chairman, H. F. Watson; Secretary, R. H. Miller, Jr.; Executive Committee, J. P. Black, H. B. Bringhurst, S. W. Marshall, B. Taylor and R. J. Trinkle. May 12. Attendance 45.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED SEPTEMBER 26, 1924

AIKENS, ANDREW JACKSON, Engineer, Inductive Coordination, Pacific Tel. & Tel. Co., 1413 Jay St., Sacramento, Calif.
ALEXANDER, THOMAS WESLEY, Jr., Engineering Assistant, The Bell Telephone Co. of Penna., 416-7th Ave., Pittsburgh; res., Crafton, Pa.
ANDERSON, FRANK LAWRENCE, Maintenance Engineer, Anderson Improvement Co., 2324 University Ave., St. Paul, Minn.
ARONOFF, SAMUEL, Electrical Engineer, Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.
AYVASIAN, MIHRAN HARRY, Electrical Draftsman, Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston; for mail, South Boston, Mass.
*BAILEY, HERBERT R., Draftsman, Portland Electric Power Co., Electric Bldg., Portland, Ore.
BARR, JOHN H., Electrical Foreman, Stone & Webster, Inc., 147 Milk St., Boston, Mass.; for mail, Terre Haute, Ind.
BATTISTA, LOUIS M., Construction Dept., Tidewater Building Corp., Farmington, Conn.
BAUD, ROBERT VICTOR, 160 E. 56th St., New York, N. Y.
BENSON, HARRY E., Pacific Tel. & Tel. Co., 1413 Jay St., Sacramento, Calif.
BISAILLION, WILFRED A., Supervisor, Berwick Electric Heater Dept., Canadian Car & Foundry Co., Turcot Works, Montreal, P. Q., Can.
BLACKWELL, EDWARD S., Asst. Supt. of Construction, Stone & Webster, Inc., 303 Electric Bldg., Seattle, Wash.
BUCHER, FRED J., Electrical Draftsman, Public Service Co. of Northern Illinois, 72 W. Adams St., Chicago, Ill.
BURCHETT, CLARENCE WILLIAM, Vice-President, Theatre Equipment Supply Co., 146 Leavenworth St., San Francisco, Calif.
CAHOON, ALLAN W., Technical Engineer, Penn Public Service Corp., Johnstown, Pa.
CAMPBELL, DONALD STILES, Material Clerk, Washington Water Power Co., Spokane, Wash.
CAMPBELL, WALLACE ROSS, Electrical Draftsman, Kansas City Power & Light Co., 1330 Grand Ave., Kansas City, Mo.
CANNIZZARO, ANTHONY, 1077 6th Ave., New York, N. Y.
CARL, ROBERT DELNO, Asst. Switchboard Operator, Philadelphia Electric Co., Trenton Ave. & Somerset St., Philadelphia, Pa.
CARMODY, RAYMOND PHILIP MICHAEL, Master Mechanic, Buffalo Steel Car Co., Inc., Buffalo, N. Y.
CLARK, FRANK MARSHALL, Physicist, General Electric Co., Pittsfield, Mass.
COBB, LAWRENCE H., Engineer of Building, Cushman & Wakefield, 244 Madison Ave., New York, N. Y.
COLE, MILTON T., Electrical Designer, Byllesby Engineering Co., 1924 Continental & Commercial Bank Blvd., Chicago, Ill.
COLLINS, EDWARD J., Design Estimator, Philadelphia Electric Co., 23rd & Market Sts., Philadelphia; res., Oak Lane, Pa.
CONRAD, WILLIAM DEWEY, Equipment Engineer, Pacific Tel. & Tel. Co., 1413 Jay St., Sacramento, Calif.
COUGHLAN, ANTHONY M. J., Inspector, Brooklyn Edison Co., Inc., 360 Pearl St., Brooklyn; res., New York, N. Y.
COXE, EDWARD H., Jr., Automatic Control Man, Substation Dept., Duquesne Light Co., Pittsburgh, Pa.
DASTOOR, MINOCHER ARDESHIR, Electrical Supervisor, Sub-Divisional Office, Military Works, Colaba, Bombay, India.
*DINAPOLI, DOMENICK PAUL, Electrical Designer, Pacific Gas & Electric Co., 445 Sutter St., San Francisco, Calif.
DUNLEAVY, BERNARD JOSEPH, Asst. in Charge of Experimental Laboratory, American Insulating Machinery Co., Fairhill & Huntingdon Sts., Philadelphia, Pa.
EGGENBERGER, JOHN BENJAMIN, Tester, United Electric Light & Power Co., 147th St., New York, N. Y.; res., Newark, N. J.
ELLIOTT, SYDNEY RAYLEIGH, Electrical Engineer, Burma Corp. Ltd., Mansam Falls, via Namyao, N. Shan States, Burma, India.
EVANS, FRANK W., Field Engineer, Westinghouse Elec. & Mfg. Co., 467 10th Ave., New York, N. Y.
FEATHERSTONE, EDWARD BRADFORD, Electrical Engineer; Teacher, Mathematics & Physics Dept., Scott & Libbey High Schools, 221 Michigan St., Toledo, Ohio.
FERGUSON, RANDON, Test Assistant, 301 Laboratory of Applied Mechanics, University of Illinois, Urbana, Ill.
FIFE, HERBERT A., Asst. to Engineer of Inside Plant, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.
FITCHETT, WILLIAM OTIS, Test Dept., General Electric Co., 89 Watsessing Ave., Bloomfield, N. J.; res., Richmond, Va.
FRY, MARVIN, Transmission Engineer, The Pacific Tel. & Tel. Co., 1413-J St., Sacramento, Calif.
GABLE, MARTIN, Salesman, Westinghouse Elec. & Mfg. Co., 912 Virginia Railway & Power Bldg., Richmond, Va.
GALLAGHER, CHARLES, c/o The Agent General for Western Australia, Savoy House, The Strand, London, Eng.
GARTH, ROBERT MARSHALL, Transformer Engineer, West Penn Power Co., West Penn Bldg., Pittsburgh; res., Wilkinsburg, Pa.
GEYER, FERDINAND HENRY, District Illuminating Engineer, Westinghouse Elec. & Mfg. Co., 30th & Walnut Sts., Philadelphia, Pa.
GOODING, CHARLES C., Transmission Engineer, Pacific Tel. & Tel' Co., 1413 Jay St., Sacramento, Calif.
GRUNSTEIN, WILLIAM, Graduate Student of Physics, Columbia University, New York, N. Y.
HALLOWELL, EDMUND M., Designing Engineer, Delta Star Electric Co., 2433 Fulton St., Chicago, Ill.
HERRSCHAFT, WILLIAM, Educational Director, Chicago School of Electricity, Div. School of Engineering of Milwaukee, Wis., 2009-11 S. Michigan Ave., Chicago, Ill.
HINCY, WILLIAM ALFRED, Student, Drexel Institute, Philadelphia; res., Media, Pa.
*HITCHCOCK, CARL HUNTLEY, Development Engineer, Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.
HITCHCOCK, WILLIAM JAMESON, 82 W. Filmore Ave., Corona, N. Y.
HODGSON, EDWARD, Engineering Dept., Marconi Wireless Telegraph Co. of Canada, Ltd., 11 St. Sacrament St., Montreal, P. Q., Can.
HOFF, NORMAN S., Engineer's Assistant, The Bell Telephone Co. of Penna., 416 7th Ave., Pittsburgh, Pa.
HOWARTH, OLIVER, Technical Engineer & Meter Superintendent, Lancashire Electric Power Co., 196 Deansgate, Manchester; res., Walkden, Eng.
IRISH, FRANCIS M., Maintenance & Operation, Electrical Equipment, Colorado Power Co., 828 Symes Bldg., Denver, Colo.
JOHNSON, GROVER C., Division Plant Engineer, Northwestern Bell Telephone Co., Fargo, N. D.
JOHNSON, RICHMOND CURRAN, Switchboard Operator, North East Power House, Kansas City Power & Light Co., Kansas City, Mo.
KLINE, FRANK WILLIAM, Electrician, Special Construction, Northern States Power Co., Minneapolis, Minn.
KOWALSKI, EDMUND W., Service Man, The Washington Water Power Co., 214 W. Main St., Pullman, Wash.
KUNDTS, ROY H., Electrician, Columbus Railway, Power & Light Co., Columbus; res., Groveport, Ohio.
LITTLE, DAVID SCOTT, District Manager, Marine Dept.. Radio Corp. of America, 10 S. La Salle St., Chicago, Ill.
MAHN, HOLBROOK, Sales Engineer, Hendrie & Bolthoff Mfg. & Supply Co., 1635 17th St., Denver, Colo.
MATSUMOTO, HISANAGA, Engineer, "Keihan" Electric Railway Co., Teumabashi, Osaka, Japan.
MAYO, JOHN EDWARD, Electrical Superintendent, Northern Peru Mining & Smelting Co., Casilla 162, Trujillo, Peru, So. Amer.
MILLMAN, MAXWELL, 25 Barrett St., Brooklyn, N. Y.
MITCHELL, DONALD HENRY, Automatic Train Control Adjuster, Atchison, Topeka & Santa Fe Railroad, Shopton, Fort Madison, Iowa.
*MYERS, VINCENT E., Engineering Dept., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
NAPPER, REX E., Construction Dept., General Electric Co., 120 Broadway, New York; res., Brooklyn, N. Y.
NEHER, JOHN HUTCHINS, Special Test Dept., Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.; for mail, Princeton, N. J.
NICHOLS, ALEXANDER GEORGE, Public Service Production Co., 54 Park Pl., Newark, N. J.
NICHOLSON, GEOFFREY CHARLTON, Student Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.
OLSON, SIGFRED GUSTAV, Field Engineer, Pacific Gas & Electric Co., 445 Sutter St., San Francisco; res., Alameda, Calif.
OSBORNE, J. IRVING, Electrician, American Smelting & Refining Co., Maurer; res., Perth Amboy, N. J.
PALMER, WALDO G., Division Plant Superintendent, The Ohio Bell Telephone Co., 724 Nasby Bldg., Toledo, Ohio.
PARMLEY, SAMUEL, Electrical Contracting, Gary, Ind.
PATTENDEN, ALBERT HENRY, Electrical Engineer, Canadian Consolidated Rubber Co., Ltd., 241 Guy St., Montreal, P. Q., Can.
QUERQUES, ANTHONY, Electrical Draftsman, Public Service Production Co., 54 Park Pl., Newark, N. J.
RAMSAY, DAVID MacPHERSON, Jr., Electrical Tester, General Electric Co., River Works, West Lynn; res., West Quincy, Mass.
RANDALL, LESTER, Electrical Engineer, Hartford Electric Light Co., 266 Pearl St., Hartford, Conn.
REEVES, CHARLES VICTOR, Standardization & Testing Dept., Edison Electric Illuminating Co. of Boston, 1165 Mass. Ave., Boston; res., Dedham, Mass.

RICHMOND, H. STANLEY, Draftsman, Columbus Railway Power & Light Co., 104 N. 3rd St., Columbus, Ohio.

*ROBERTSON, WALTER GRAY, Engineer, Construction Dept., General Electric Co., 627 Greenwich St., New York, N. Y.

ROGERS, PRICE LAZARD, Assistant to H. Berkeley Hackett, 505 Chestnut St., Philadelphia, Pa.

*RUSSELL, EARL EVERETT, Student Transmission Engineer, Pacific Tel. & Tel. Co., 1413 Jay St., Sacramento, Calif.

SALERNO, ARTHUR A., Asst. Construction Engineer, Consolidated Tel. & Elect. Subway Co., 54 Lafayette St., New York, N. Y.

SCHAFFER, JOHN HENRY, Electrical Construction Inspector, Thomas E. Murray, Inc., 132nd St. & Locust Ave., New York; res., College Point, N. Y.

SCHREADER, AMBROSE HENRY, Electrical Contractor, 106 N. Meramec Ave., Clayton, Mo.

SHAFFER, FRANK JAMES, Load Dispatcher, The Ohio Public Service Co., Mansfield, Ohio.

SHARMAN, FRANK H., Electrician, Pullman Co., New York, res., Nassau Haven, N. Y.

SMITH, ARTHUR V., General Line Foreman, The Counties Gas & Electric Co., 120 W. Penn St., Norristown, Pa.

SOLBERG, JOHANNES STAFF, Gibbs & Hill, Pennsylvania Station, New York; res., Brooklyn, N. Y.

SQUIRE, HENRY HERBERT, Jr., Instructor, Works Training Division, Hawthorne Works, Western Electric Co., Inc., Chicago; res., Cicero, Ill.

*STEMBEL, DAVID MAYNARD, Asst. Engineer of Distribution, Union Gas & Electric Co., 1107 Plum St., Cincinnati, Ohio.

STOCK, HENRY F., Manager, Acme Electric Co., 2121 E. 39th St., Kansas City, Mo.

STOCKER, LESTER J., Operator, Public Electric & Gas Co., 19 Chauncey St., Trenton, N. J.

*STOVER, PETER ALBERT, Asst. to General Supt., Iowa Electric Co., 402 S. 21st St., Cedar Rapids, Iowa.

SWARD, CECIL WILLIAM, Sales Engineer, G. & W. Electric Specialty Co., 7440 S. Chicago Ave., Chicago, Ill.

TARANIK, JAMES S., Electrical Draftsman, Pacific Gas & Electric Co., 567 Sutter St., San Francisco, Cal.

TATA, NARIMAN NUSSERWANJI D., Transmission Line Inspector, The Andhra Valley Power Supply Co., Ltd., Camp Dharavi, Bombay, India.

THOMAS, WILBER COVER, District Transmission Engineer, The Pacific Tel. & Tel. Co., Los Angeles, Calif.

*TOTH, JOSEPH, Jr., Contractor, Fairfield, Conn.

*TURNER, ROBERT E., Pennsylvania Water & Power Co., Holtwood, Pa.

UHL, J. FRANKLIN, Sales Engineer, National Carbon Co., Inc., 551 W. Monroe St., Chicago, Ill.

WAGNER, MICHAEL AMBROSE, Distribution Engineer, Pinellas County Power Co., St. Petersburg, Fla.

WARNER, STANLEY FREDERICK, Chief, Small Apparatus Inspection Development & Methods Section, Western Electric Co., Inc., Hawthorne Sta., Chicago, Ill.

WATTS, THOMAS S., Switchboard Engg. Section, Westinghouse Elec. & Mfg. Co., 30th & Walnut Sts., Philadelphia, Pa.

WEBSTER, ISRAEL, Asst. Electrical Engineer, Borough Council, Hamilton, New Zealand.

*WEEKS, JAMES LUTHER, Jr., Test Course, Western Electric Co., Inc., 268 W. 36th St., New York; res., Brooklyn, N. Y.

WHITE, HARRY, Lighting Specialist, in Charge of Lamp Dept., American Electric Co., 124 S. 8th St., St. Joseph, Mo.

*WIELAND, HERBERT GEORGE, General Tester, New York Edison Co., 92 Vandam St., New York, N. Y.

WINSTANLEY, PETER HOULT, Telephone Engineer, Siemens Brothers & Co., Ltd., 807 MacArthur Bldg., Winnipeg, Man., Can.

*WOOD, ORLA LESLIE, Jr., Testing Dept., General Electric Co., Schenectady, N. Y.

YOSHIMURA, TEIJI, Electrical Engineer, Bureau of Electric Power, Ministry of Communications, Tokio, Japan

YOUNGS, CHARLES L., Primary Meter Man & Assistant to Electrical Meter Superintendent, Board of Water & Electric Light Commissioners, Lansing, Mich.

ZIPSE, ARTHUR ERNEST, Sales Engineer, G. & W. Electric Specialty Co., 7440 So. Chicago, Ave., Chicago, Ill.

Total 113

*Formerly Enrolled Students

ASSOCIATES REELECTED SEPTEMBER 26, 1924

SCHOLZ, WILLIAM PAUL, Asst. Engineer, Elec. Dept., Interborough Rapid Transit Co., 165 Broadway, New York, N. Y.

McGAHEY, CALVERT R., Sales Engineer, Worthington Pump & Machinery Corp., 435 Trust Co. of Georgia Bldg., Atlanta, Ga.

VAN KURAN, KARL E., District Manager, Westinghouse Elec. & Mfg. Co., 420 S. San Pedro St., Los Angeles, Calif.

MEMBER RELECTED SEPTEMBER 26, 1924

SMITH, CARLETON WHITNEY, Asst. Engineer, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

ASSOCIATE REINSTATED SEPTEMBER 26, 1924

ELDRED, CALVIN POWELL, Plant Engineer, Abrasive Co., & John A. Manning Paper Co., Troy, N. Y.

MEMBERS ELECTED SEPTEMBER 26, 1924

CARHART, FRANK MILTON, Consulting Engineer, Jackson & Moreland, 387 Washington St., Boston, Mass.

DAVIS, E. KENT, Electrical & Mechanical Engineer, Peale Interests, St. Benedict, Pa.

ERIKSON, PER ENGELBERT, Asst. Chief Engineer, International Western Electric Co., Connaught House, Aldwych, London, W. C. 2, England

HILL, FREDERICK WILLIAM LANDIS, Distribution Engineer, Electric Bond & Share Co., 71 Broadway, New York, N. Y.

HOLMES, JAMES THOMAS, Electrical Engineer, I. P. Frink, Inc., 239-10th Ave., New York, N. Y.

JUNKINS, ALBERT BENTON, Electrical Engineer, American Sugar Refining Co., Key Highway-East, Baltimore, Md.

LACY, THOMAS NORMAN, Division Plant Superintendent, Long Lines Dept., American Tel. & Tel. Co., 1422 Hurt Bldg., Atlanta, Ga.

MESTRAUD, ANDRE, Asst. Chief Electric Dept., Societe Generale d'Entreprises, 56 Faubourg, St. Honore, Paris, France

PATTERSON, LUCIUS LAMAR, Professor, Elec. Engg. Dept., Mississippi Agricultural & Mechanical College, A. & M. College, Miss.

PERKINS, LAWRENCE M., Electrical Design Engineer, Motor Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

ROSENTHAL, HENRY, Engineer, L. L. Summers & Co., 140 Nassau St., New York, N. Y.

SPRATT, WILLIAM WARD, General Engineer, Paper Mill Section, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Pittsburgh, Pa.

WHITTLESEY, WILLIAM A., President & Manager, Pittsfield Electric Co., Pittsfield, Mass.

TRANSFERRED TO GRADE OF FELLOW SEPTEMBER 26, 1924

HOBBINS, WILLIAM D., Chief Engineer, Wisconsin Telephone Co., Milwaukee, Wis.

WILLEY, FRANK W., Member of Firm, Willey Wray Electric Co., Cincinnati, Ohio

TRANSFERRRED TO GRADE OF MEMBER SEPTEMBER 26, 1924

GOFF, HAROLD W., Designing Engineer, Western Electric Co., New York, N. Y.

KNAPP, PETER R., Assistant Superintendent, Electric Department, Toledo Edison Co., Toledo, Ohio

SCHWABE, WALTER P., Vice-President & General Manager, Northern Connecticut Light & Power Co., Thompsonville, Conn.

SMITH, WALTER H., Railway Equipment Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held September 22, 1924, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

GREENWOOD, LEON H., Telephone Engineer, American Telephone & Telegraph Co., New York, N. Y.

MILLER, HERMAN P., Jr., Radio Engineer, Federal Telegraph Co., Palo Alto, Calif.

STRAUS, HENRY L., Member of Firm, Industrial Power Equipment Co., Baltimore, Md.

THATCHER, RENO E., Service Superintendent, Puget Sound Power & Light Co., Seattle, Wash.

WOODRUFF, LOUIS F., Instructor in Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

YOE, HARRY A., Assistant Engineer, New York Central Railroad Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before Octobber 31, 1924.

Aldrich, K. B., Puget Sound Power & Light Co., Seattle, Wash.

Alpern, D. K., Mass. Institute of Technology, Cambridge, Mass.

Attarian, E. G., Brooklyn Rapid Transit Testing Bureau, Brooklyn, N. Y.

Ballman, E. C., Balder Electric Co., St. Louis, Mo.

(Applicant for re-election.)

Brearley, R. J., Shawinigan Water & Power Co., Shawinigan Falls, P. Q., Can.

Brown, J. E., Cornell University, Ithaca, N. Y.

Brown, T., 181 E. 120th St., New York, N. Y.

Callahan, E. F., International General Electric Co., Inc., Schenectady, N. Y.

(Applicant for re-election.)

Caraza, E., Electrical Contractor, Estacion Del Rio, Edo., Mexico.

Cole, W. G., Armature Winder, Westwood, Calif.

Cottell, V. G., New York Edison Co., New York, N. Y.

Davison, J. M., Fabrica de Cocolapam, Orizaba, Vera Cruz, Mex.

Davison, R. T., Cia Industrial de Orizaba S. A., Rio Blanco, Vera Cruz, Mex.

(Applicant for re-election.)

Easterbrook, J. F. (Member), Yale Club, New York, N. Y.

(Applicant for re-election)

French, G. B., Landers, Frary & Clark, Hartford, Conn.

Glassford, C. G., The Pacific Tel. & Tel. Co., San Francisco, Calif.
Hannah, G. M., Chesapeake & Potomac Tel. Co., Baltimore, Md.
Headings, W. W., Pittsburgh Reflector Co., Pittsburgh, Pa.
(Applicant for re-election.)
Hillegass, H. H., The Bell Telephone Co. of Penn., Philadelphia, Pa.
(Applicant for re-election.)
Hughes, G. N., W. E. Biggs Engineering Co., Knoxville, Tenn.
Ingham, F. E., (Member), Westinghouse Elec. Int. Co., New York, N. Y.
Kahn, J. L., 202 South St., Oyster Bay, N. Y.
Kells, D. G., New York Edison Co., New York, N. Y.
Lehr, E. E., (Member), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
(Applicant for re-election.)
Masshard, H. J., Public Service Production Co., Newark, N. J.
Maurer, A. A., Western Electric Co., Inc., Hawthorne, Chicago, Ill.
McCreary, H. J., Western Electric Co., Inc., Chicago, Ill.
McGee, J. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McGilvray, J. R., Gibbs Bros., Inc., New York, N. Y.
Melsome-Smith, C. H., (Member), Manufacturers Rep. in Aus., San Francisco, Calif.
Mockel, R., Brooklyn Edison Co., Brooklyn, N. Y.
Montgomery, W., (Member), Warner Sugar Co. of Cuba, Central Miranda, Miranda, Oriente, Cuba.
Motsek, P., Tkach & Motsek, Jersey City, N. J.
Naudain, M. C., American Sheet & Tin Plate Co., Vandergrift, Pa.
Noble, N. A., Western Electric Co., Inc., Chicago, Ill.
Nutter, L. H., General Electric Co., Schenectady, N. Y.
O'Brien, F. G., 186 Ege Ave., Jersey City, N. J.
O'Brien, P., Manhattan Eye, Ear & Throat Hospital, New York, N. Y.
Ortmann, F. J., Eastern Connecticut Power Co., Norwich, Conn.
Perreten, A. E., Public Service Co. of Colorado, Boulder, Colo.
Pilsbury, C. C., General Electric Co., Pittsfield, Mass.
Reguenga, I. M., Electric Bond & Share Co., New York, N. Y.
Reydon, H., Public Service Production Co., Newark, N. J.
Rice, W. B., Western Electric Co., Inc., Philadelphia, Pa.
Richards, W., Weirton Steel Co., Weirton, West Va.
Schulze, H. C., General Electric Co., Schenectady, N. Y.
Seippel, C. P., Electric Bond & Share Co., New York, N. Y.
Smith, H. J., Western Electric Co., Inc., New York, N. Y.
Stangeby, S. A., Adirondack Power & Light Corp., Schenectady, N. Y.
Tate, D. C., Western Electric Co., Inc., Hawthorne Station, Chicago, Ill.
Thomson, H., New York Edison Co., New York, N. Y.
Tozier, E. S., Eastman Kodak Co., Kodak Park, Rochester, N. Y.
Vidal, H. B., Westinghouse Elec. & Mfg. Co., Niagara Falls, N. Y.
Vreeland, F. P., (Member), 271 E. Hayes Ave., Corona, N. Y.
(Applicant for re-election.)
Wittenberg, M., (Member), 115 E. Mosholu Parkway North, New York, N. Y.
Total 55.

FOREIGN

Goodman, H. R., Hydro Branch, Public Works Dept., Wellington, N. Z.
Leckey, G. W., Hydro-Electric Dept., Hobart, Tasmania, Aus.
Osolobe, Y., Electrical Engineer, Brno-Kr. Pole, Czechoslovakia
Pardoe, L. G., British Thomson-Houston Co., Rugby, Eng.
Tailby, A. J., Te Awamutu Electric Power Board, Te Awamutu, N. Z.
Tregurtha, F. C. P., Metropolitan-Vickers Elec. Co., Ltd., Trafford Park, Manchester, Eng.
Total 6.

STUDENTS ENROLLED SEPTEMBER 26, 1924

19101 Tucker, William E., Jr., Mass. Institute of Technology.
19102 Grueter, Francis J., Mass. Inst. of Tech.
19103 Lusignan, Joseph T., Jr., Mass. Institute of Technology.
19104 Black, Freeman C., University of Southern California.
19105 Kingsbury, Herbert F., Northeastern University.
19106 Shaffer, Lee J., University of Akron.
19107 O'Donovan, Richard L., Mass. Institute of Technology.
Total 7.

Officers A. I. E. E. 1924-1925

PRESIDENT
(Term expires July 31, 1925)
FARLEY OSGOOD

JUNIOR PAST-PRESIDENTS

(Term expires July 31, 1925)	(Term expires July 31, 1926)
FRANK B. JEWETT	HARRIS J. RYAN

VICE-PRESIDENTS

(Terms expire July 31, 1925)	(Terms expire July 31, 1926)
J. E. MACDONALD (District No. 8)	EDWARD BENNETT (District No. 5)
HERBERT S. SANDS (District No. 6)	JOHN HARISBERGER (District No. 9)
S.E.M.HENDERSON (District No.10)	HAROLD B. SMITH (District No. 1)
H. E. BUSSEY (District No. 4)	L. F. MOREHOUSE (District No. 3)
WILLIAM F. JAMES (District No. 2)	H. W. EALES (District No. 7)

MANAGERS

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Utah	H. W. Clark	John Salberg, W. E. & M. Co., Walker Bank Bldg., Salt Lake City, Utah
Vancouver	C. N. Beebe	A. Vilstrup, B. C. Electric Railway Co., 425 Carroll St., Vancouver, B. C.
Washington, D. C.	J. H. Ferry	Frank R. Mueller, Bliss Electrical School, Washington, D. C.
Worcester	S. M. Anson	Fred B. Crosby, 15 Belmont St., Worcester, Mass.

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LIST OF BRANCHES

Name and Location	Chairman	Secretary
Alabama Poly Inst., Auburn, Ala.	R. A. Betts	A.E. Duran
Alabama, Univ. of, University, Ala.	L. L. Evans	C. M. Lang
Arizona, Univ. of, Tucson, Ariz.	Edward Moyle	James A. Wilson
Arkansas, Univ. of, Fayetteville, Ark.	Hugh McCain	R. T. Purdy
Armour Inst. of Tech., Chicago, Ill.	D. E. Richardson	J. S. Farrell
Brooklyn Poly Inst., Brooklyn, N. Y.	H. B. Hanstein	J. H. Loerch
Bucknell Univ., Lewisburg, Pa.	E. S. Hopler	A. L. Huffman
California Inst. of Tech., Pasadena	W. A. Lewis	A. E. Schueler
California, Univ. of, Berkeley, Calif.	F. C. Blocksom	M. Nutting
Carnegie Inst. of Tech., Pittsburgh, Pa.	P. M. Hissom	D. Beecher
Case School of Applied Science, Cleveland, O.	H. P. Davis	George Geyser
Catholic Univ. of America, Washington, D. C.	C. G. Kirby	J. W. Dolan
Cincinnati, Univ. of, Cincinnati, O.	R. T. Congleton	W. C. Osterbrook
Clarkson Coll. of Tech., Potsdam, N.Y.	L. L. Merrill	E. T. Augustine
Clemson Agri. College, Clemson College, S. C.	R. W. Pugh	O. A. Roberts
Colorado State Agri. Coll., Ft. Collins	Frank Ayres	Lyndall Hands
Colorado, Univ. of, Boulder, Colo.	G. Cartwright	W. T. Crossman
Cooper Union, New York	E. J. Kennedy	A. W. Carlson
Denver, Univ. of, Denver, Colo.	C. G. Diller	Ray Hoover
Drexel Institute, Philadelphia, Pa.	J. P. Carr	W. P. Turner
Florida, Univ. of, Gainesville, Fla.	J. R. Benton	Geo. Harrison
Georgia School of Tech., Atlanta, Ga.	R. A. Goodburn	J. A. Minor
Iowa State College, Ames, Iowa	V. Womeldorf	G. G. Thomas
Iowa, Univ. of, Iowa City, Iowa	G. C. K. Johnson	C. A. Von Hoene
Kansas State College, Manhattan	V. O. Clements	W. K. Lockhart
Kansas, Univ. of, Lawrence, Kans.	C. H. Freese	G. R. Vernon
Kentucky, Univ. of, Lexington, Ky.	K. R. Smith	J D. Taggart
Lafayette College, Easton, Pa.	Wm. Welsh	J. B. Powell
Lehigh Univ., S. Bethlehem, Pa.	E. W. Baker	D. C. Luce
Lewis Institute, Chicago, Ill.	E. Millison	C. P Meek
Maine, Univ. of, Orono, Me.	H. L. Kelley	H. E. Bragg
Marquette Univ., Milwaukee, Wis.	W. J. Hebard	C. Legler
Massachusetts Inst. of Tech., Cambridge, Mass.	G. P. Davis	F. J. Hecht, Jr.
Michigan Agri. Coll., East Lansing	C. M. Park	O. Dausman
Michigan, Univ. of, Ann Arbor, Mich.	F. J. Goellner	M. H. Lloyd
Milwaukee, Engg. School of, Milwaukee, Wis.	I. L. Illing	A. U. Stearns
Minnesota, Univ. of, Minneapolis	R. W. Kellar	H. R. Reed
Missouri, Univ. of, Columbia, Mo.	M. P. Weinbach	
Montana State Coll., Bozeman, Mont.	Jack Cowan	J. A. Thaler
Nebraska, Univ. of, Lincoln, Neb.	H. Edgerton	O. A. Andrews
Nevada, Univ. of, Reno, Nev.	C. Hicks	G. Fairbrother
North Carolina State College, Raleigh, N. C.	A. C. Bangs	J. C. Richert, Jr.
North Carolina, Univ. of, Chapel Hill	T. B. Smiley	H. L. Coe
North Dakota, Univ. of, University	S. J. Nogosek	T. E. Lee
Northeastern Univ., Boston, Mass.	L. F. Hubby	E. G. Crockett
Notre Dame, Univ. of, Notre Dame, Ind.	Frank Egan	K. Faiver
Ohio Northern Univ., Ada, Ohio	Mr. Cotner	J. K. Fulks
Ohio State Univ., Columbus, O.	T. A. McCann	R. E. Madden
Oklahoma A. & M. Coll., Stillwater	F. C. Todd	R. W. Twidwell
Oklahoma, Univ. of, Norman, Okla.	R. B Greene	M F Hill
Oregon Agri. Coll., Corvallis, Ore	M P. Bailey	E. E. Bricker
Pennsylvania State College, State College, Pa.	C. MacGuffie	J. H. Schmidt
Pennsylvania, Univ. of, Philadelphia	H. W. Steinhoff	J. W. Emling
Pittsburgh, Univ. of, Pittsburgh, Pa.	G. H. Campbell	F. Wills
Purdue Univ., Lafayette, Ind.	S. B. Mills	M. G. Seim
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Rhode Island State Coll. Kingston, R.I.	C. S. North	D. Brown
Rose Poly. Inst., Terre Haute, Ind.	P. Wilkens	R. A. Reddie
Rutgers College, New Brunswick, N. J.	E. G. Riley	E. J. Butler
South Dakota, Univ. of, Vermillion, S. D.	E. N. Clarke	S. M. Lawton
Southern California, Univ. of, Los Angeles, Calif.	H. A. McCarter	Chet Little
Stanford Univ., Stanford University, Calif.	M. L. Wiedmann	A. C. Wright
Swarthmore Coll., Swarthmore, Pa.	A. L. Williams	S. R. Keare
Syracuse Univ., Syracuse, N. Y.	E. J. Agnew	J. G. Hummel
Tennessee, Univ. of, Knoxville, Tenn.	S. R. Woods	W. T. Elliott
Texas A. & M. Coll., College Station	A. A. Ward	L. H. Cardwell
Texas, Univ. of, Austin, Tex.	G. C. Hengy	W. K. Sonnemann
Utah, Univ. of, Salt Lake City, Utah	I. J. Kaar	M. B. McCullough
Virginia Military Inst., Lexington	H. F. Watson	R. H. Miller, Jr.
Virginia Poly. Inst., Blacksburg, Va.	F. L. McClung	E. M. Melton
Virginia, Univ. of, University, Va.	T. S. Martin, Jr.	J. W. McNair
Washington, State Coll. of, Pullman	J. Dunkin	J. T. Yasumura
Washington Univ., St. Louis, Mo.	H. Spoehrer	C. M. Dunn
Washington, Univ. of, Seattle, Wash.	John Weir	J. W. Lewis
West Virginia Univ., Morgantown	O. A. Brown	James Copley
Wisconsin, Univ. of, Madison, Wis.	H. G. Holmes	K. E. Wooldridge
Yale Univ., New Haven, Conn.	W. C. Downing, Jr.	O. B. Skinner

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Amperehour Meters.—Bulletin 68, 24 pp. Describes type "N" Sangamo amperehour meters. Sangamo Electric Company, Springfield, Ill.

Transmission Line Accessories.—Catalog 24, 192 pp. Describes "Hubbard" pole line hardware and "Peirce" construction specialties. Hubbard & Company, Pittsburgh, Pa.

Vertical Alternator.—Bulletin 840, 4 pp. Describes E-M vertical alternators and lists representative installations. Electric Machinery Mfg. Company, Minneapolis, Minn.

Permeameter.—Bulletin, 8 pp. Describes the "Fahy" Simplex permeameter, laminated yoke type, for magnetic testing of ferrous materials. Frank P. Fahy, 50 Church Street, New York.

Blowers.—Bulletin 1103, 36 pp. Describes "American" H. S. fans for steam power plants. American Blower Company, Detroit, Mich.

Apparatus for Measuring Conductivity of Electrolytes.—Catalog 48, 32 pp. Describes typical equipment, instruments, accessories and methods for measuring electrolytic resistance. The Leeds & Northrup Company, 4901 Stenton Avenue, Philadelphia, Pa.

Resistors.—Bulletin, 4 pp. Describes the "Monitor" edgewound resistor for higher voltages, made in standard units that can be bolted together and connected in series or parallel, as conditions may require. Monitor Controller Company, Baltimore, Md.

Electric Equipment for Railroad Shops.—Bulletin C 1661. Is intended to assist engineers in solving the electrical problems frequently encountered in increasing shop facilities or changing or adding to existing equipment. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Auto Transformers.—Bulletin 1020, 4 pp. Describes a standard line of 2 to 1 auto transformers, or balancing coils, for three wire, 110-volt distribution in factories. The bulletin also illustrates the mounting for all standard air cooled transformers. American Transformer Company, 178 Emmet St., Newark, N. J.

Outdoor Substation and Transmission Line Equipment.—Bulletins describing "Memco" insulator clamps, caps, fittings for substations, splicing sleeves and tools, choke coils, air break switches, heavy duty disconnecting switches and carbon grounds. Memco Engineering & Manufacturing Co., Inc., 381 Hamilton Street, Long Island City, N. Y.

Elevator Controllers.—Bulletin 3082, 48 pp. Describes many types of elevator control apparatus for passenger and freight elevators. A section is devoted to auxiliary apparatus for use with elevator controllers, including reversing switches, floor selectors, various limit switches, car switches and door switches. The Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

Potheads.—Bulletin 24, 16 pp. A pocket size booklet primarily intended for the construction engineer as a guide to the installation of G & W potheads. It is also useful to the engineer in layout work, as it contains illustrations of the various mechanical details and drawings of different parts of potheads. G & W Electric Specialty Company, 7440 So. Chicago Avenue, Chicago, Ill.

Automatic Station Control Equipment.—Bulletin 47731, 28 pp. Describes briefly the uses and advantages of this type of equipment. The greater part of the bulletin is given over to a list of installations up to January 1, 1924, giving the name of the company, station, type of apparatus, kilowatt capacity and incoming and outgoing voltage. General Electric Company, Schenectady, N. Y.

Micarta.—Circular 1686, 16 pp. Describes the applications in which the standard forms of Micarta may be employed in central stations and substations. The methods of applying micarta on bus bars, connections, and in making cable joints; its use for barriers on circuit breakers and switches; its employment as bushings, slot wedges and cleats, and the miscellaneous uses to which it may be put are fully covered in the publication, which also includes the electrical and mechanical properties of the different grades of micarta. Westinghouse Electric & Mfg. Company, Pittsburgh, Pa.

T-Connectors.—Catalog 1, 16 pp. Describes "Burndy" T-Connectors for use with copper tubing, cable or solid busses, especially for outdoor sub-stations. The design of these connectors embodies features which assure full electrical contact, without dependance on bolts, under all conditions of weather and electrical strain, to which outdoor equipment is subjected. Engineering data covering dimensions, properties and current capacities of tubings and cables, is included. Burndy Engineering Company, 10 East 43rd Street, New York.

NOTES OF THE INDUSTRY

The Wagner Electric Corporation, St. Louis, Mo., announces the appointment of D. K. Rivas, as manager of its New York office.

The Economy Fuse & Mfg. Company, Chicago, Ill., announces that on September 8th its Minneapolis district sales Office was removed to 1008 Marquette Avenue.

Triumph Electric Company, Cincinnati, O.—Frank A. Wilch, who has been associated with the Cleveland office of the company, has been placed in charge of that territory, succeeding Edward S. Ford.

The Sangamo Electric Company, Springfield, Ill., has appointed L. Brandenburger, as its agent at Salt Lake City, Utah. Mr. Bradenburger who has long been connected with the electrical industry, is local representative for a number of other prominent electrical manufacturers.

The Roller-Smith Company, 12 Park Place, New York, announces the appointment of the Thrall Electric Company, Havana, as its exclusive representative in the island of Cuba, for the complete line of Roller-Smith instruments and circuit breakers.

Western Electric Company Sales Increase.—An increase of $37,676,000 in the sales of the Western Electric Company is reported for the first eight months of 1924, during which the billings reached a total of $195,167,000. Orders received during the first eight months of this year totalled $198,892,000 or $7,566,000 more than the orders received during the same period of 1923.

Ingersoll-Rand Company, New York, announces the appointment of L. G. Coleman as manager of the locomotive department, which has been organized to handle the new oil electric locomotive. Mr. Coleman was previously assistant general manager of the Boston & Maine Railroad.

W. L. Garrison, who has been in the engineering department of the company for a number of years has been appointed assistant manager of the same department.

College Undergraduates take Westinghouse Summer Course.—Sixteen different colleges and universities in the United States were represented in the group of twenty-five students who took the junior graduate engineering course at the East Pittsburgh Works of the Westinghouse Electric & Manufacturing Company. This is the first time a regular course of instruction has been offered by the Westinghouse Company during the summer months for men who are yet to complete their college courses.